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Re: Effect of Humic Acid on Floatability of Coal and Pyrite

Dear Dr. Moon:

Enclosed please find ten copies of our final report.

Yours sincerely,

Dr. J. Laskowski
Project Manager

EFFECT OF HUMIC ACID ON FLOATABILITY OF COAL AND PYRITE

Final Report

by

Department of Mining and Mineral Process Engineering
The University of British Columbia
Vancouver, B. C.

Project Manager: J. S. Laskowski, Eng., Ph.D., D.Sc.

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ABSTRACT

Humic acid has been shown to adsorb on graphite, coal and coal-pyrite and to modify the surface properties of these minerals. The surface of a hydrophobic solid, such as graphite, becomes quite hydrophilic in the presence of humic acid, and the floatability of graphite is effectively depressed in a few ppm humic acid solutions. The effect of humic acid is more pronounced in the presence of inorganic electrolytes (KCl, KNO_3).

Humic acid was shown to depress coal as well as pyrite. It was found that the amount of humic acid needed for depression varies for different coals.

Flotation of the pyrite containing DEVCO coal in the presence of humic acid produces concentrates with a lower content of sulphur, but the yield of concentrate is also reduced.

INTRODUCTION

The flotation of hydrophobic solids such as graphite, coals, sulphur, talc, et cetera, is based on natural differences in hydrophobicity between the valuable mineral and gangue particles. In the case of coal, use of water-insoluble nonpolar oils (collectors) in the presence of water-soluble surfactants (frothers) increases the difference in natural wettability of the floatable (coal) and non-floatable mineral components.

Three main factors can be claimed to be mainly responsible for surface properties of coal particles[1]:

(i) Hydrocarbon skeleton (related to rank)

(ii) Oxygen functional groups

(iii) Inorganic impurities

To detect the effect of the first two, carefully cleaned coal samples containing only low amounts of inherent inorganic matter, have to be used in the experiments.

Surface properties of coal, as it has recently been demonstrated[2,3] clearly depend on the number of surface oxygen functional groups: carboxylic and phenolic. However, in the real flotation process, oxidation of coal can change not only a number of oxygen functional groups on its surface, but can also produce inorganic soluble species (multivalent metal complexes[4]), or organic soluble substances (humic acids). The former were shown to affect coal floatability particularly at some pH values; the latter, as recently demonstrated by Firth and Nicol[5], can appreciably reduce flotation selectivity.

The effect of oxidation on surface properties of coal was also investigated by J. Leja and his co-workers.[6,7] Five samples from a freshly opened adit in the Fording River Coal deposits in British Columbia were taken at selected distances from the surface to a depth of 45.7 m. Results indicated a progressive decrease in oxidation from a very high level in the surface sample to a relatively low oxidation level for samples taken at 27.9 m and 45.7 m[6]. The same coal samples used in the flotation studies produced less intense coloration in the flotation pulp in the case of deep-mined samples (less oxidized). The oxidized samples could be floated only in the acid pH range following prolonged desliming under alkaline conditions[7].

Humic acids are highly reactive, amorphous, acidic, predominantly aromatic, chemically complex polyelectrolytes.[8,9] They are defined as those components of humus which are soluble in strong bases, but insoluble in strong acids. They fall into the category of colloidal macromolecules and are present in practically all natural water systems. Under the pH conditions of most natural water they are negatively charged. The dissociation constants of carboxyl and phenolic groups are 4.5-4.9 and 8 - 8.7, respectively.

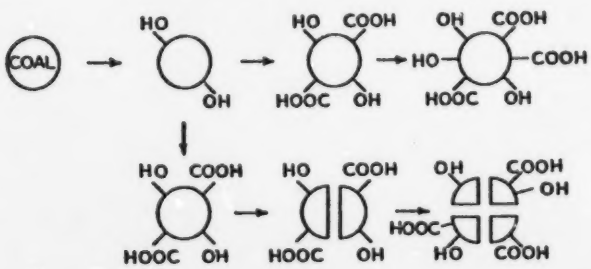
Humic acid forms complexes with metal ions, clays and other aluminosilicate minerals. A model for the structure of humic acids put forward by Wershaw et al[8] pictures the humic particles as forming both homogenous and heterogenous aggregates. The homogenous aggregates are composed of chemically similar molecules. The heterogenous or mixed aggregates can be composed of different types of molecules or of different homogenous aggregates. The pH affects both the charge density and configuration of

the humic macromolecules; the size of the aggregates is a function of pH but is also affected by oxidation with molecular oxygen and air, especially in alkaline solutions.[9,10]

The molecular weight of humic acids can range from less than 600 to more than 10,000. Jensen et al[11] found that total acidity of coal (carboxyl and phenolic groups content) increases steadily with oxidation of coal under dry conditions while conversion of coal to humic acids depends strongly on oxidation temperature, and was appreciable only in the temperature range above 200°C.

Coal oxidation, according to these authors, involves two simultaneous but unrelated reactions which result in the development of acidity and skeletal breakdown, respectively. This suggests that alkali solubility (humic acids) is mainly a consequence of degradation.

Increase in coal acidity



Increase in amount of alkali soluble matter
(humic acid)

It may then be concluded that each coal, depending on its degree of oxidation, contains some surface carboxylic and phenolic groups. It can also contain humic acids, which are soluble under alkaline conditions.

It is worth pointing out that Yarar and Leja[7] found that oxidized coal, which did not float, produced intense coloration in the flotation pulp.

Humic materials impart a brown or yellow color to natural waters. The estimated size of humic macromolecules is in the range of 3.5 - 10 nm after which they are classified as colloidal matter. As such,humic acids are usually removed from water by coagulation with alum, followed by sedimentation and filtration. Cationic polyethylenimine polymers (PEI) were shown to destabilize the humic acid aqueous solution very efficiently at pH 5.5 - 6[12,13,14]. The process is based on neutralization of the anionic functional groups by the cationic PEI molecules, as illustrated below:

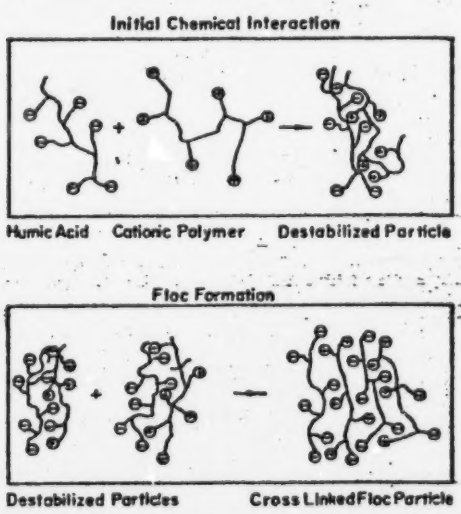


Figure 4. Schematic representation of humic acid/PEI destabilization and aggregation

Klute[15] investigated flocculation of colloidal silica with cationic polyelectrolyte in the presence of low amounts of humic acid. The polyelectrolyte adsorption and particle aggregation were significantly

influenced by the amount of humic acid present in solution and he found that due to fast chemical reaction between the polyelectrolyte and free humic acid, higher flocculant doses were necessary for the flocculation of colloidal silica.

Babenko[16] described the strong effect of humic acid on the floatability of ilmenite and zircon. Depression was observed when anionic collectors were applied. On the other hand, cationic flotation in the presence of humic acid gave even better results.

Safin[17] used electrochemical methods to intensify the extraction of humic acids from lignites. Cathodic reduction of lignite suspension in 0.5% NaOH aqueous solution, carried out at 15 mA/cm^2 for 45 minutes, doubled the rate of humic extraction. Such an electrochemical treatment was also claimed to change the flotation properties of humic acid and similar phenomena was observed with electro-oxidized ligninosulphonate. The effect of electrochemical treatment on the subsequent properties of humic acid solutions can be explained by the redox properties of humic acids, which are due to the presence of quinoid and nitrogen-containing groups.[18] It seems that the amount of quinoines in humic matter may vary according to the initial raw material and the method of preparation.

Humic acid has recently been reported to cause steric stabilization of hematite aqueous suspensions.[19] Adsorption of humic acid on hematite was shown to depend strongly on $CaCl_2$ concentration.

To understand the behaviour of humic acid at hydrophobic solid/aqueous solution interface, and its subsequent effect on the properties of hydrophobic solid suspension, graphite was used as a model system in the first part of the work. Then various samples of Fording River Coal deposit

investigated and described by Leja et al[6] were used in the batch flotation experiments with humic acid. Coal pyrite was used in other series of experiments and preliminary data on the flotation of coal containing pyrite in the presence of humic acid are given in the last part of the report.

PART I. EFFECT OF HUMIC ACID ON THE PROPERTIES OF GRAPHITE SUSPENSIONS

Materials and Methods

High quality Ceylon graphite sample was supplied by Ward's Natural Science establishment. Size fraction below 38μm was used in the adsorption tests and Hallimond flotation experiments were carried out with the use of a -105 + 74μm sample.

Aldrich sodium salt of humic acid was used as supplied, without purification. Solutions of 0.2 g/liter in distilled water were utilized as stock solutions.

In the adsorption tests, 0.5 g of graphite was conditioned at 25°C. and 250 r.p.m. for 30 minutes with 50 ml. of humic acid solution at a given concentration and pH. A Lab-line Environ Shaker (Lab-line Instruments Inc., Illinois) was used to condition all samples under temperature and hydrodynamic controlled conditions. pH was measured before and after conditioning and the final values were used in plotting the data.

Concentration of humic acid in aqueous solutions was determined with the use of a Perkin Elmer Coleman 124 Spectrophotometer. UV spectra of humic acid aqueous solutions in the range from 200 nm to 550 nm are shown in Fig. 1. They agree well with those reported in the literature.[20] The adsorbance plotted versus concentrations of humic acid at 300 nm and 400 nm gives straight lines, as shown in Fig. 2, and these straight calibration lines were used in our adsorption studies as the adsorption density was determined from the difference in humic acid concentration before and after adsorption. The small effect of the pH on the adsorbance, as shown in Fig. 3, was neglected in the calculation of the amount of humic acid adsorbed.

Particle size distribution of the -37μm graphite fraction was measured with a Computerized Electrozone Celloscope (Particle Data Inc.) similar in principle to a Coulter Counter. Particle size distribution was measured in 0.75% NaCl solution in the presence of 100 ppm carboxymethyl cellulose. Median surface diameter (diameter of equal-surface sphere) was found to be 16.9μm and simple calculation gave 1650 cm^2/g. This value was further used to recalculate adsorption density expressed per unit mass into adsorption per unit surface area.

Measurements of electrokinetic potential were made using a Riddick Zeta-meter. For each measurement about 20 mg of the -37μm graphite was contacted with humic acid solution of desired concentration and pH and allowed to settle. Supernatant with fine graphite particles was further utilized. Experiments at a constant ionic strength using 10^{-2} KCl or KNO_3 were also conducted. In each case it took about 30 minutes from the immersion of the solid with the solution to the first measurements. Points shown in the figures are mean values for ten readings.

In the contact angle measurements the polished specimens of graphite were conditioned with the reagents. Then the free bubble of about 1 mm in diameter was placed on the surface of the graphite and 2 minutes later the angle was measured on both sides of the bubble. The measurements were repeated a few times, and mean values are reported.

Flotation experiments in a modified Hallimond tube with a porous fit at the bottom end and a magnetic stirrer were carried out under similar conditions. Nitrogen flow was kept constant at 30 cc/min. and flotation time was 3 minutes.

Results

Adsorption isotherms of humic acid on graphite at pH 4.5 are shown in Fig. 4. As might have been anticipated, density of adsorption attained higher values for increased ionic strength of the solution. This is also seen in Fig. 5 showing the effect of pH on adsorption. In the whole range of pH investigated, the adsorption increases with ionic strength.

Fig. 6 shows the effect of humic acid on the zeta potential of graphite at pH 4.5. As seen, the zeta potential is slightly more negative in 10^{-2}M KCl but falls rapidly towards more negative values in the presence of 10^{-2} KNO_3. This trend is further confirmed by Fig. 7. In the whole range of pH the zeta potential of graphite was more negative in the presence of potassium nitrate. The zeta potential of graphite is more negative in the whole pH range in the presence of humic acid (Figs. 7 and 8).

The contact angle data are given in Fig. 9. As seen, the hydrophobicity of graphite is very efficiently reduced by humic acid. The surface of graphite becomes entirely hydrophilic at very low concentrations of humic acid in the presence of KCl and even lower concentrations of humic acid are required when KNO_3 is used. The effect of pH on the contact angle is given in Fig. 10.

Reuse of the same piece of graphite in the experiments required prolonged treatment with alkaline solutions followed by rinsing with distilled water and repolishing. Without such preparation the graphite specimens were quite hydrophilic and the results were not reproducible.

Figs. 11 and 12 demonstrate that humic acid is quite an efficient depressant of graphite flotation. The effect of humic acid, as noted in the previous experiments, is stronger in the presence of electrolytes; KNO_3 was again revealed to influence the action of humic acid much more strongly than the other electrolytes. As seen in Fig. 11, 1 to 2 ppm humic acid in the presence of 10^{-2} KNO_3 depresses graphite floatability as strongly as 10 ppm humic acid alone.

Discussion

Adsorption isotherms indicate clearly that the humic acid is appreciably adsorbed by a hydrophobic solid such as graphite. At small concentrations of humic acid, the uptake is almost complete. An increase in the ionic strength of the solution increases adsorption density, probably through salting out effects.

The experiments confirmed the strongly anionic character of the humic acid. Its adsorption decreases with pH and is appreciable in the acidic range when the graphite was less negatively charged.

The zeta potential measurements revealed that the graphite used in our experiments was negatively charged in the whole range of pH investigated. In the presence of humic acid the zeta potential increases in negative directions in the whole pH range. The increase of the zeta potential in the negative direction is especially clear at very low concentrations of humic acid (below 10 ppm); a further increase in humic acid concentration does not affect the zeta potential greatly (Fig. 6). This low concentration range corresponds with the first part of the adsorption isotherm. Almost all depression of the graphite floatability

occurs in the same range of low humic acid concentrations. After saturation coverage, the addition of excess reagent does not improve depression.

Floatability of graphite depends quite clearly on the pH which reflects contribution of the electrical charge to the wettability, and this dependence is almost completely eliminated in the presence of humic acid.

The effect of humic acid on floatability of graphite described in this paper is very similar to the effect of carboxymethyl cellulose, guar and gum arabic on the floatability of talc, discussed in the paper by Steenberg and Harris.[21]

The relationship between contact angle and concentration of humic acid corresponds very well with the floatability of graphite. In flotation (Fig. 11) as well as contact angle measurements (Fig. 9) a strong effect of the conditioning time with humic acid on final results was revealed. This was especially true in the case of aqueous solutions without any supporting electrolyte. In the presence of electrolytes, the time needed to reach equilibrium was apparently much shorter, and the effect of the conditioning time was not then so pronounced.

The results indicate that nitrate ions do not behave as the indifferent electrolyte. The zeta potential of graphite was more negative in the presence of KNO_3 in the whole pH range. Salting out effects were also much stronger in the presence of KNO_3 than KCl.

All experiments confirmed that the colloidal character of humic acid solutions makes these substances extremely sensitive toward the presence

of electrolytes. The effect of humic acid on the measured properties (adsorption, wettability, zeta potential, floatability) were always much more pronounced in the presence of electrolytes. The effect of conditioning time clearly seen when distilled water was used, was always reduced in the presence of electrolytes.

PART II. FLOATABILITY OF COAL AND PYRITE IN THE PRESENCE OF HUMIC ACID

Materials

Three samples of Fording River coal, described by J. Leja and co-workers[6], were used in initial experiments. As indicated in the quoted paper, these samples are characterized by a progressive decrease in oxidation from a very high level for the surface sample, to a relatively low oxidation level for samples taken at 22.9 m and 45.7 m distances. The content of carboxylic groups in these samples is given in Fig. 13 after J. Leja et al.[6]

Conditioning of the 25 g samples of the -425 mesh Fording River Coal with 500 ml of 10^{-2}M KCl solution at room temperature for 30 minutes revealed that a small amount of humic acid was leached out from the coal under such conditions. As seen from 14, the concentration of humic acid in the pulp after conditioning depends on the degree of coal oxidation. The more the Fording River coal was oxidized, the higher was the concentration of humic acid after conditioning.

The Fording River coal was crushed below 0.6 mm for flotation experiments.

Two other pyrite-containing coal samples (DEVCO, Sydney, Nova Scotia) used in our experiments were sent in by CANMET. They were crushed in the same way. Characteristics of the samples used are given in Table I.

The coal-pyrite used in our experiments was separated from the high sulphur DEVCO coal by means of a super panner. -106 + 53μm size fraction was used in a Hallimond flotation and adsorption test.

Batch flotation tests were carried out with the use of the Denver cell modified in the way described by Roberts et al.[22] Experimental details are given in Fig. 15.

Zeta Potential and Floatability of Fording River coal in the presence of humic acid

The tests on adsorption of humic acid on the less oxidized deeper coal (45.7 m) were inconclusive. After 30 minutes of shaking there was no detectable humic acid left in the solution in any of the samples, even when the initial concentration of humic acid was 100 ppm. These results mean that 0.5 g of the coal adsorbed all of the humic acid present in 50 ml of 100 ppm solution.

The tests on the effect of pH on humic acid adsorption were inconclusive. The pH of the pulp constantly dropped to values between 3.4 and 4.3 after 30 minutes of shaking for initial pH being 4.0 and 12.5, respectively.

The effect of the pH and humic acid concentration on the zeta potential of Fording River coal (45.7 m) is shown in Figs. 16, 17 and 18. As in the case of graphite, the zeta potential values were more negative in the presence of humic acid in the whole range of pH. However, this effect was not as pronounced as in the experiments with graphite. Also, the floatability of coal in the presence of humic acid was not very different from that carried out without humic acid. It must be borne in mind, however, that the floatability in the Hallimond tube was studied without the use of flotation reagents, and the floatability of coal under such conditions is poor.

Fig. 20 shows the effect of humic acid on the flotation kinetics of Fording River coal floated with MIBC. These experiments were also carried out in a Hallimond tube and they demonstrate that the rate of coal flotation decreases in the presence of humic acid.

Adsorption of Humic Acid onto Pyrite and its Effect on Pyrite Floatability

Adsorption isotherm for the humic acid on coal-pyrite separated from the high sulphur DEVCO coal is given in Fig. 21. The pulp had a strong buffering effect and the final pH after 30 minutes shaking was always around 7, even if the initial pHs were in the range from 4 to 10. Results seem to indicate that in the presence of xanthate, the adsorption of humic acid is reduced in the range of its low concentrations, but is enhanced in the range of high humic acid concentrations. This may indicate competition for the surface sites at low concentrations and co-adsorption at the higher concentrations.

Figs. 22 and 23 show that the coal-pyrite floats well in the acidic range, as expected. However, this was also the range where the humic acid showed a strong depressing effect. Ore-pyrite used in our experiments behaved quite differently. Humic acid strongly depressed its flotation in the acidic range; however, its flotation in the pH range from 6.5 to 9 seemed to be improved in the presence of humic acid, as shown in Fig. 24. This relationship should be studied further with the use of various pyrite samples, as it may have a very important implication in the flotation of coal aimed at lowering its sulphur content.

In addition to the results shown in Figs. 22 and 23, some other examples of the effect of humic acid on the rate of flotation of coal-

pyrite are given in Fig. 25. The experiments were conducted in a Hallimond tube. To study flotation kinetics, the material floated in the concentrate stem was measured as a function of time. At the end of the experiments the fraction of material in the concentrate stem was collected, filtered, dried and weighed. This enabled calculation of a factor for each experiment which was used to convert the height of the bed of the floated portion to the fraction floated. Experiments run in this way, at pH 7, indicate a decrease in the rate of coal-pyrite flotation in the presence of humic acid, as shown in Fig. 25. The limited amount of coal-pyrite did not allow us to conduct similar experiments at other pH values.

PART III. BATCH FLOTATION OF THE FORDING RIVER COAL AND THE DEVCO COAL

Fording River Coal

The batch flotation results obtained with the Fording River coal are illustrated in Figs. 26 through 29. Three samples of the Fording River coal, oxidized to a different degree as indicated in Fig. 13, were floated with 960 g/t kerosene and 80 g/t MIBC. Kerosene had been emulsified in an aqueous solution of MIBC (20% of the total amount of MIBC used was introduced into the pulp with emulsified kerosene) prior to adding into the flotation pulp.

As shown in Fig. 26, Fording River coal mined at 22.9 m distant from the surface, floated quite well in the cleaning flotation stage, even in the presence of high amounts of humic acid (up to 1,5 kg/t). Two other Fording River coal samples mined at 45.7 m and 11.6 m began to be depressed in the cleaning stage when 0.5 kg/t of humic acid was added.

Flotation concentrates were subjected to sieve analyses after drying. Fig. 27 indicates that in the case of Fording River coal mined from the 45.7 level, efficient depression was achieved at 1 kg/t humic acid, but flotation was improved with a further increase in concentration of humic acid. In all cases, flotation of coarse fractions seem to be improved when higher doses of humic acid were applied. Higher additions of humic acid clearly decrease the rate of flotation and, under such conditions, the coarser fractions appear in the froth after the first minutes of flotation.

Devco Coal

The results on flotation of the low sulphur DEVCO coal with MIBC only are given in Table II.

Concentrates obtained with 100 and 200 g/t MIBC contain only 5.1 and 5.7T ash, respectively, but in both cases over 3% of S_T. Flotation results with 200 g/t MIBC in the presence of 2.5 kg/t humic acid are given in the table for comparison. These indicate that sulphur content can be reduced by adding humic acid, but at the expense of recovery; the yield under such conditions dropped to 33,4%.

Tables III and IV present the results of flotation of low sulphur DEVCO coal with kerosene and MIBC utilizing humic acid in the cleaning stage. These results are illustrated in Fig. 30. The figure shows that sulphur content in the cleaned concentrate decreases parallel to the yield. Surprisingly, in both cases--that is with 360 g/t kerosene and 200 g/t MIBC as well as 960 g/t kerosene and 80 g/t MIBC--a similar depression was achieved with humic acid.

Table V presents flotation results with the high sulphur DEVCO coal which are plotted in Fig. 31. In this case concentrates containing much below 3% S_T have been obtained. 0,5 kg/t humic acid in the cleaning stage gave 2.35% S_T at around 50% yield of concentrate.

Size analyses of the concentrate cleaned with the use of humic acid are given in Figs. 32 and 33. Results presented in Fig. 33 bear close resemblance to Fig. 27 showing cleaning of the Fording River coal (45.7m). In both cases flotation was improved at high doses of humic acid.

Flotation kinetics data are given in Tables VI and VII and are presented in a graphical form in Figs. 34 and 35. It is to be noted that almost all our batch flotation experiments have been carried out at pH close to 5. According to Figs. 22 and 23 at such pH values, humic acid depresses pyrite flotation. Low sulphur DEVCO coal floated in the presence of humic acid with MIBC alone (Fig. 34) or with kerosene (Fig. 35)

and produced concentrates with sulphur content below 3%.

Results presented in Fig. 35 indicate that after a few minutes of flotation with humic acid, a new dose of kerosene can effectively restore flotation.

An alternative method, i.e. flotation of pyrite with xanthate while keeping coal depressed with humic acid, did not seem to work out as both coal and pyrite turned out to be effectively depressed under such conditions.

DISCUSSIONS AND CONCLUSIONS

The results presented in this report indicate that humic acid adsorbs in appreciable quantities onto a hydrophobic solid such as graphite and to an even higher extent on coal. Humic acid also adsorbs onto coal-pyrite. The pyrite, however, displayed significantly different adsorption properties in the presence of xanthate. In the range of low concentrations of humic acid, the density of humic acid adsorption was lower in the presence of xanthate, but in the range of higher concentrations of humic acid, the presence of xanthate increased the density of humic acid adsorption, probably through the co-adsorption phenomena.

Adsorption of humic acid was shown to increase the negative electrical charge of graphite and coal in the whole range of pH investigated. Hydrophobic graphite surfaces become quite hydrophilic in humic acid solutions. As a result, humic acid efficiently depresses the floatability of graphite and coal.

The tests carried out with different coals revealed that the amount of humic acid needed for efficient depression can be very different.

The effect of humic acid on the floatability of pyrite was found to be pH dependent. In the acid range of pH, depression occurs.

Studies on coal-pyrite separation described in this report must be regarded as very preliminary ones. Limited amount of the coal-containing pyrite samples, as well as a very limited budget, did not allow extensive studies to be undertaken. The DEVCO coal was floated after it had been crushed below 600 μm. It is very doubtful whether such feed preparation had liberated all pyrite.[23] Only total sulphur

was determined in the separation products; organic and pyritic sulphur contents have not been identified.

Since humic acid was found to depress strongly the floatability of hydrophobic solids (graphite coal), at first the reverse flotation was tried out by floating pyrite while depressing coal in the cleaning stage. Depression of pyrite turned out, however, to be as efficient as depression of coal and therefore an alternative route, i.e. direct coal flotation with depression of pyrite, has been attempted. These results seem to be promising and the project should be continued.

However, before conducting any further flotation tests, the liberation of pyrite and coal should be studied extensively and, in consequence, the more completely liberated feed should be used in the experiments. Only under such conditions may the effect of humic acid on coal-pyrite separation be fully elucidated.

Our experiments revealed that MIBC as well as kerosene provide lower sulphur grades when applied together with humic acid in the direct flotation of the DEVCO coal. It will probably be possible to achieve this without losing much coal when proper flotation conditions are selected. It is interesting that the depressing properties of humic acid seem to cease after the first few minutes of flotation, and another addition of kerosene restores flotation completely.

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TABLE I

Ash and Total Sulphur (S_T) Analyses of the coal Samples Used in the Present Investigation

Particle Size	% Wt.	% Assay		% Distribution	
		Ash	S_T	Ash	S_T
Fording River Coal (45.7 m)					
-600 + 425 µm	21.4	13.40	-	21.0	
-425 + 300 µm	19.5	11.42		16.4	
-300 + 212 µm	17.1	21.56		27.2	
-212 + 106 µm	19.4	11.20		16.0	
- 106 µm	22.6	11.60		19.3	
HEAD	100.0	13.6		99.9	
Fording River Coal (22.9 m)					
-600 + 425 µm	23.0	19.25		27.2	
-425 + 300 µm	21.2	15.80		20.6	
-300 + 212 µm	17.4	16.70		17.9	
-212 + 106 µm	17.8	16.08		17.6	
- 106 µm	20.6	13.20		16.7	
HEAD	100.0	16.3		100.0	
Fording River Coal (11.6 m)					
-600 + 425 µm	25.8	17.0		27.3	
-425 + 300 µm	18.6	15.50		18.0	
-300 + 212 µm	15.8	16.42		16.1	
-212 + 106 µm	18.7	15.13		17.6	
- 106 µm	21.1	15.90		21.0	
HEAD	100.0	16.05		100.0	

TABLE 1 (Continued)

Particle Size	% Wt.	% Assay		% Distribution	
		Ash	S_T	Ash	S_T
Low Sulphur DEVCO Coal					
-600 + 425 µm	25.5	7.56	3.76	25.85	22.2
-425 + 300 µm	19.9	6.87	4.96	18.35	22.8
-300 + 212 µm	14.8	6.88	4.57	13.65	15.6
-212 + 106 µm	16.8	6.95	4.05	15.65	15.7
- 106 µm	22.9	8.63	4.46	26.5	23.7
HEAD	99.9	7.45	4.32	100.0	100.0
High Sulphur DEVCO Coal					
-600 + 425 µm	24.5	9.82	3.43	26.2	17.2
-425 + 300 µm	21.5	8.61	6.43	20.1	28.3
-300 + 212 µm	17.3	8.60	4.72	16.1	16.7
-212 + 106 µm	17.7	7.41	4.80	14.3	17.4
- 106 µm	18.8	11.40	5.29	23.3	20.4
HEAD	99.8	9.2	4.88	100.0	100.0

TABLE II

Flotation of Low Sulphur DEVCO Coal
using MIBC only. Flotation time 4 minutes

Size Fractions µm	100 g/t MIBC, pH 5.2					
	Concentrate			Tailings		
	γ, %	Ash %	S_T, %	γ, %	Ash %	S_T, %
-600 + 425	9.8	9.36	2,95	9.4	9.47	5.89
-425 + 300	9.7	4.6	2.91	8.7	7.8	5.15
-300 + 212	8.1	3.8	2.89	8.6	9.03	4.57
-212 + 106	15.2	4.0	2.79	6.2	11.16	5.39
- 106	23.0	6,77	4.07	1.3	36,55	20.75
HEAD	65.8	5.1	3.29	34.2	10.27	5.84

Size Fractions µm	200 g/t MIBC, pH 5.4					
	Concentrate			Tailings		
	γ, %	Ash %	S_T, %	γ, %	Ash %	S_T, %
-600 + 425	7.6	4.6	2.91	12.2	14.3	5.96
-425 + 300	11.2	4.4	2.77	8.3	11.4	6.26
-300 + 212	14.5	5.0	2,97	4.1	14,86	9,39
-212 + 106	18.9	5.3	3.36	2.0	28,27	14.11
- 106	20.5	7.8	4.41	0.7	41.49	21.34
HEAD	72.7	5.73	3.44	27.3	15.22	7.56

Size Fractions µm	200 g/t MIBC, pH 11.2					
	Concentrate			Tailings		
	γ %	Ash %	S_T, %	γ %	Ash %	S_T, %
-600 + 425	7.5	4.70	3.02	13.4	7.96	4.99
-425 + 300	8.7	4.51	2.95	11.2	8.39	4.97
-300 + 212	9.1	4.48	2.85	8.5	8.43	7.73
-212 + 106	13.2	4.74	3.24	7.0	13.14	4.10
- 106	19.7	7.4	3.81	1.6	32.95	13.7
HEAD	58.2	5.56	3.30	41.7	10.0	5.73

Flotation Products	2.5 hg/t humic acid + 200 g/t MIBC, pH 5.4			
	Concentrate		Tailings	
	γ, %	S_T, %	γ, %	S_T, %
	33.4	2.80	66.4	4.41

Table III. Flotation of low sulphur DEVCO coal with 360 g/t kerosene and 200 g/t MIBC, pH 4.8 - 5.6 Cleaning with the indicated amount of humic acid.

Primary tailings	γ, %	S_T, %
- 600 +425 um	3.7	11.4
- 425 +300 um	1.5	14.4
- 300 +212 um	0.7	23.6
- 212 +106 um	0.4	18.4
- 106 um	0.3	26.6

Size fraction um	Cleaning Flotation							
	No humic acid				0.5 kg/t humic acid			
	concentrate		tailings		concentrate		tailings	
	γ, %	S_T, %	γ, %	S_T	γ, %	S_T, %	γ, %	S_T, %
-600 + 425	11.8	2.98	4.4	4.76	7.4	2.61	9.1	4.83
-425 + 300	16.3	3.14	2.4	10.0	11.0	2.70	7.8	5.36
-300 + 212	17.0	3.33	0.8	16.1	12.9	2.84	4.4	5.97
-212 + 106	19.3	4.57	0.8	11.0	17.1	3.11	4.3	7.14
- 106	20.1	4.30	0.5	17.7	17.3	3.63	1.9	15.2
HEAD	84.5	3.76	8.9	15.4	65.7	3.06	27.5	6.24

Size fraction um	1 kg/t humic acid				2.5 kg/t humic acid					
	Concentrate		tailings		Concentrate 1		Conc. 2		Tailings	
	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %
-600 + 425	5.3	2.73	8.3	4.0	3.5	2.58	5.7	2.92	7.5	4.42
-425 + 300	7.8	2.59	9.2	4.19	5.7	2.61	5.0	2.99	7.6	3.90
-300 + 212	7.2	3.1	8.2	4.7	4.3	2.8	2.5	3.0	11.1	3.84
-212 + 106	7.9	2.4	15.6	4.5	2.2	2.64	0.7	2.85	19.7	3.50
- 106	15.4	3.1	8.4	7.1	1.3	2.93	1.5	2.9	15.1	5.7
HEAD	43.6	2.83	49.7	4.83	17.0	2.68	15.4	2.95	61.0	4.2

TABLE IV

Flotation of low sulphur DEVCO coal with 960 g/t emulsified kerosene and 80 g/t MIBC, pH 4-5. Cleaning with the indicated amount of humic acid

Primary Tailings	γ,%	S_T, %
-600 + 425 µm	3.8	10.9
-425 + 300 µm	1.9	11.9
-300 + 212 µm	1.3	12.5
-212 + 106 µm	0.9	12.9
- 106 µm	0.9	21.8
HEAD	8.9	12.7

Size Fraction µm	CLEANING									
	No humid acid				0.5 kg/t humic acid					
	Concentrate		Tailings		Conc. 1		Conc.2		Tailings	
	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%
-600 + 425	19.1	3.7	5.2	4.7	7.8	2.7	1.0	2.1	8.2	4.25
-425 + 300	16.0	5.2	1.9	5.5	9.2	3.1	0.4	2.6	7.0	4.95
-300 + 212	13.6	1.9	1.2	5.8	10.2	3.2	0.2	3.5	5.2	5.5
-212 + 106	14.1	3.75	1.0	8.4	19.5	3.8	0.5	4.5	4.2	7.1
-106	16.7	4.3	0.9	17.9	19.2	4.1	1.2	5.7	2.4	13.9
HEAD	79.7	3.8	10.2	6.5	60.9	3.54	3.3	3.9	27.0	5.5

Size Fraction µm	CLEANING											
	0.5 kg/t humic acid						1 kg/t humic acid					
	Conc. 1		Conc. 2		Tailings		Conc. 1		Conc. 2		Tailings	
	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%
-600 + 425	9.5	2.65	1.3	2.9	9.3	4.1	7.9	2.7	1.9	2.86	9.6	4.0
-425 + 300	10.1	2.75	0.5	2.9	8.1	4.7	6.2	2.65	0.9	2.80	10.6	4.45
-300 + 216	10.5	2.9	0.3	3.05	5.3	5.75	5.2	2.63	0.5	3.3	10.4	4.7
-216 + 106	13.0	3.1	0.4	3.65	3.4	5,4	9.2	2.43	0.6	2.8	8.2	5.5
- 106	16.2	4.05	0.8	3.85	2.6	12.4	15.1	3.5	1.5	2.9	5.7	9.5
HEAD	59.3	3.2	3.3	3.3	28.7	5.5	43.6	2.9	5.4	2.9	44.5	5.25

Size Fraction µm	CLEANING					
	2.5 kg humic acid					
	Conc. 1		Conc. 2		Tailing	
	γ,%	S_T,%	γ,%	S_T,%	γ,%	S_T,%
-600 + 425	7.5	2.69	1.7	2.8	8.0	
-425 + 300	6.0	2.82	0.9	3.0	10,1	
-300 + 216	2.4	2.9	0,4	2.77	13.1	
-216 + 106	1.0	2,76	0.7	2.87	17.2	
- 106	2.7	3,32	2.1	2.47	17,5	
HEAD	19.6	2.84	5.8	2.71	65,9	

TABLE V

Flotation of High Sulphur DEVCO Coal with 960 g/t Emulsified Kerosene and 80 g/t MIBC, pH 5 - 5.5. Cleaning with the indicated amount of humic acid.

Primary Tailings	γ, %	S_T, %
-600 + 425	1.2	11.4
-425 + 300	0.9	14.8
-300 + 212	0,7	17.2
-212 + 106	0,7	20.5
- 106	0.5	28.8
HEAD	4.0	17.2

Size Fraction µm	CLEANING									
	No humic acid				0.5 kg/t humic acid					
	Concentrate		Tailings		Conc. 1		Conc. 2		Tailings	
	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %
-600 + 425	13.1	2.01	3.5	3.92	8.7	1.81	2.2	1.63	11.4	2.66
-425 + 300	14.5	3.79	2.6	4.95	7.6	1.96	1.0	2.05	10.7	2.76
-300 + 212	15.8	2.66	2.1	4.59	7.8	2.08	0.4	2.05	7.4	2.85
-212 + 106	19.4	2.40	1.3	5.10	10.9	2.47	0.5	2.22	4.8	6.80
- 106	23.2	4.27	0.6	19.1	13.7	4.12	0.9	2.47	7.8	8.99
HEAD	86.0	3.12	9.8	5.4	48.7	2.35	5.0	1.95	42.1	4.36

Size Fraction µm	CLEANING											
	1 kg/t humic acid						2.5 kg/t humic acid					
	Conc. 1		Conc. 2		Tailings		Conc. 1		Conc. 2		Tailings	
	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %	γ, %	S_T, %
-600 + 425	9	2.07	1.8	1.69	10.1	1.92	11.7	2.71	3.2	1.49	10.9	2.21
-425 + 300	6.2	2.48	1.0	1.57	13.8	1.80	6.7	2.58	1.2	2.17	11.6	2.27
-300 + 212	1.7	2.48	0.5	1.41	15.3	2.01	2.0	2.98	0.4	3.00	13.7	2.72
-212 + 106	0.7	1.53	0.7	1.62	16.6	2.47	0.6	2.59	0.5	2.42	16.2	4.05
- 106	3.4	1.92	2.1	1.92	12.6	3.30	1.8	2.79	1.3	2.05	14.0	3.69
HEAD	21.0	2.18	6.1	1.72	68.4	2.30	22.8	2.7	6.6	1.88	66.4	3.08

TABLE VI

FLOTATION KINETICS OF LOW SULPHUR DEVCO COAL

300 g/t emulsified kerosene + 200 g/t MIBC, pH 5.7

Products	Yield %	ΣYield, %	S_T,%	ΣS_T,%	S_T Distribution %
1st Conc.	92.2	92.2	4.89	4.89	86.2
2nd Conc.	1.7	93.8	4.49	4.88	1.4
3rd Conc.	0.6	94.4	5.23	4.89	0.6
Tailings	5.6	100.0	11.0		11.8

2.5 hg/t humic acid 250 g/t KAmX + 200 g/t MIBC, pH 6:2
After 6 minutes of flotation additional 300 g/t emulsified kerosene

Products	Yield %	ΣYield %	S_T,%	ΣS_T,%	S_T Distribution %
1st. Conc.	13.8	13.8	4.77	4.77	14.2
2nd Conc.	10.9	24.7	2.98	3.98	7.0
3rd Conc.	9.5	34.2	3.08	3.75	6.3
4th Conc.	7.5	41.7	3.32	3.65	5.4
5th Conc.	54.6	56.3	4.89	4.35	57.5
6th Conc.	0.2	96.5	5.41	4.36	0.2
Tailings	3.6	100.1	12.21	4.65	9.5

300 g/t emulsified kerosene + 200 g/t MIBC + 2.5 kg/t humic acid, pH - 6.1
After 6 minutes of flotation additional 250 g/t KAmX.

Products	Yield %	ΣYield %	S_T,%	ΣS_T,%	S_T Distribution %
1st Conc.	9.1	9.1	2.69	2.69	3.4
2nd Conc.	9.3	18.4	2.74	2.72	5.7
3rd Conc.	7.5	25.9	3.12	2.83	5.2
4th Conc.	6.1	32.0	2.93	2.85	4.0
5th Conc.	5.4	37.4	3.14	2.89	3.8
6th Conc.	5.8	43.2	2.88	2.89	3.7
7th Conc.	10.9	54.1	4.83	3.28	11.7
Tailings	46.1	100.2	5.90	4.49	60.5

2.5 kg/t humic acid + 500 g/t KAmX + 200 g/6 MIBC, pH 5.8. After four minutes of flotation, 300 g/t emulsified kerosene + 190 g/t MIBC

Flotation Products	Yield, %	Σ Yield, %	S_T, %	Σ S_T, %	S_T Distribution %
1st Conc.	12.7	12.7	3.10	3.10	8.5
2nd Conc.	9.6	21.3	2.99	3.05	6.2
3rd Conc.	8.2	30.5	2.66	2.94	4.7
4th Conc.	7.3	37.8	2.66	2.89	4.2
5th Conc.	43.3	81.1	4.18	3.57	39.1
Tailings	18.9	100.0	9.11	4.62	37.2

500 g/t KAmX + 2.5 kg/t humic acid + 200 g/t MIBC, pH 6.1; 250 g/t KAmX added after six minutes of flotation.

Flotation Products	Yield, %	Σ Yield, %	S_T, %	Σ S_T, %	S_T Distribution %
1st Conc.	10.8	10.8	3.01	3.01	7.4
2nd Conc.	7.6	18.4	2.88	2.95	5.0
3rd Conc.	6.2	24.6	3.51	3.09	4.9
4th Conc.	6.4	31.0	3.13	3.10	4.5
5th Conc.	6.3	37.3	3.02	3.09	4.3
6th Conc.	5.3	42.6	3.19	3.10	3.8
7th Conc.	33.1	75.7	3.52	3.28	26.4
Tailings	24.3	100.0	7.93	4.41	43.7

TABLE VII

Flotation Kinetics of Low Sulphur DEVCO Coal

200 g/t MIBC, pH = 5.4

Flotation Products	γ,%	S_T,%	ΣS_T,%	S_T Distribution,%
1st Concentrate	40.5	3.32	3.22	26.2
2nd Concentrate	14.0	3.92	3.5	10.6
3rd Concentrate	7.8	3.70	3.5	5.6
4th Concentrate	6.3	3.53	3.5	4.3
Tailings	31.3	8.74	--	53.2
HEAD	99.9	5.14		

2.5 kg humic acid + 200 g/t MIBC, pH = 5.4

Flotation Products	γ,%	S_T,%	ΣS_T,%	S_T Distribution,%
1st Conc.	9.0	2.87	2.87	6.7
2nd Conc.	8.9	2.70	2.8	6.2
3rd Conc.	8.1	2.62	2.73	5.5
4th Conc.	7.4	3.04	2.79	5.8
5th Conc.	7.2	2.96	2.82	5.5
Tailings	59.4	4.57		70.3
HEAD	100.0	3.86		

2.5 kg/t humic acid + 500 g/t KAmX + 200 g/t MIBC, pH 7.2
360 g/t emulsified kerosene after five minutes of flotation

Flotation products	,%	S_T,%	S_T,%	S_T Distribution,%
1st Conc.	14.9	3.80	3.80	12.6
2nd Conc.	11.9	3.37	3.60	8.9
3rd Conc.	9.3	3.27	3.52	6.8
4th Conc.	8.8	3.15	3.45	6.2
5th Conc.	6.7	3.07	3.4	4.6
6th Conc.	42.5	4.52	3.9	42.7
Tailings	5.9	13.9		18.2
HEAD	100.0	4.49		

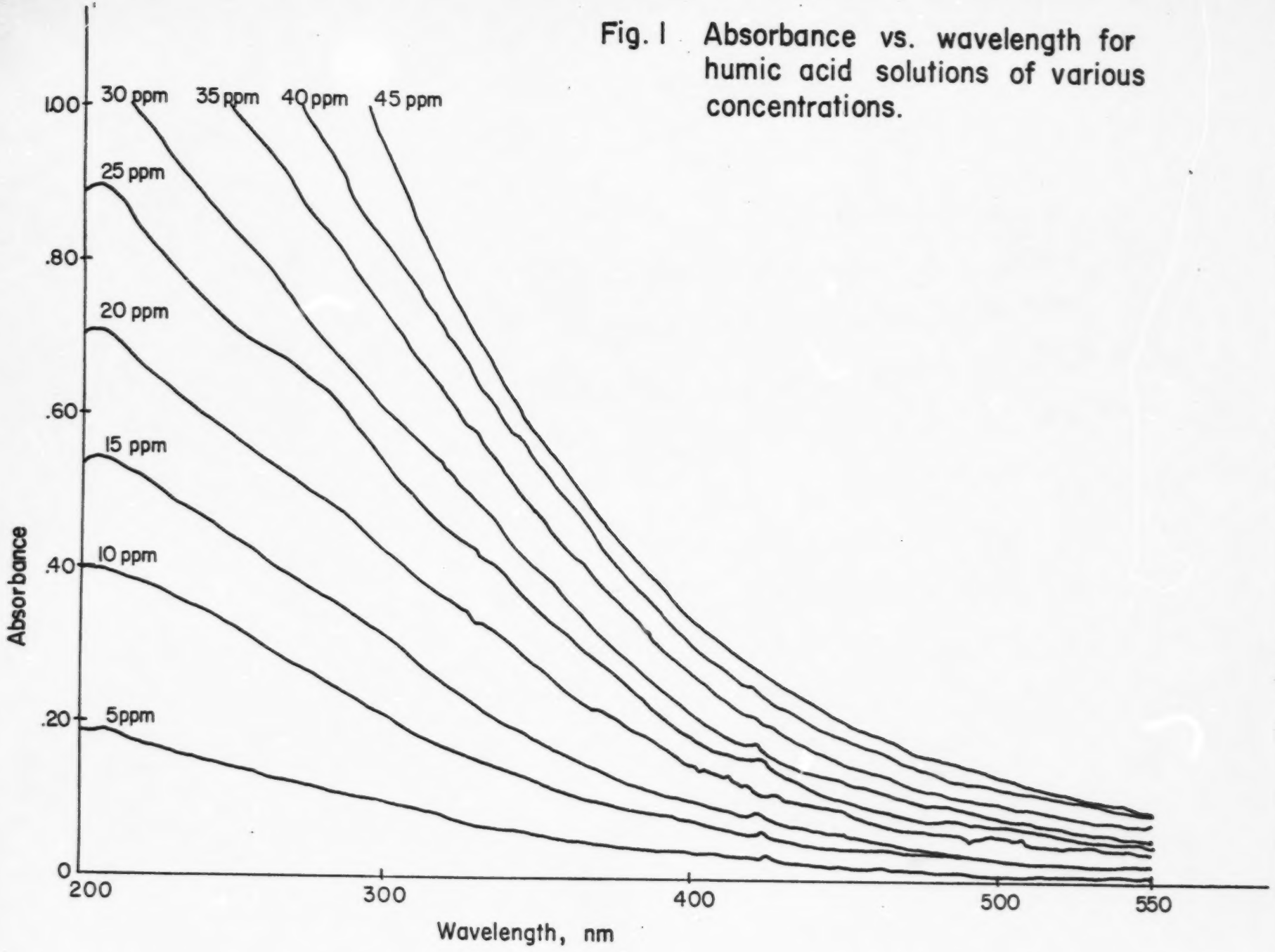


Fig. 1 Absorbance vs. wavelength for humic acid solutions of various concentrations.

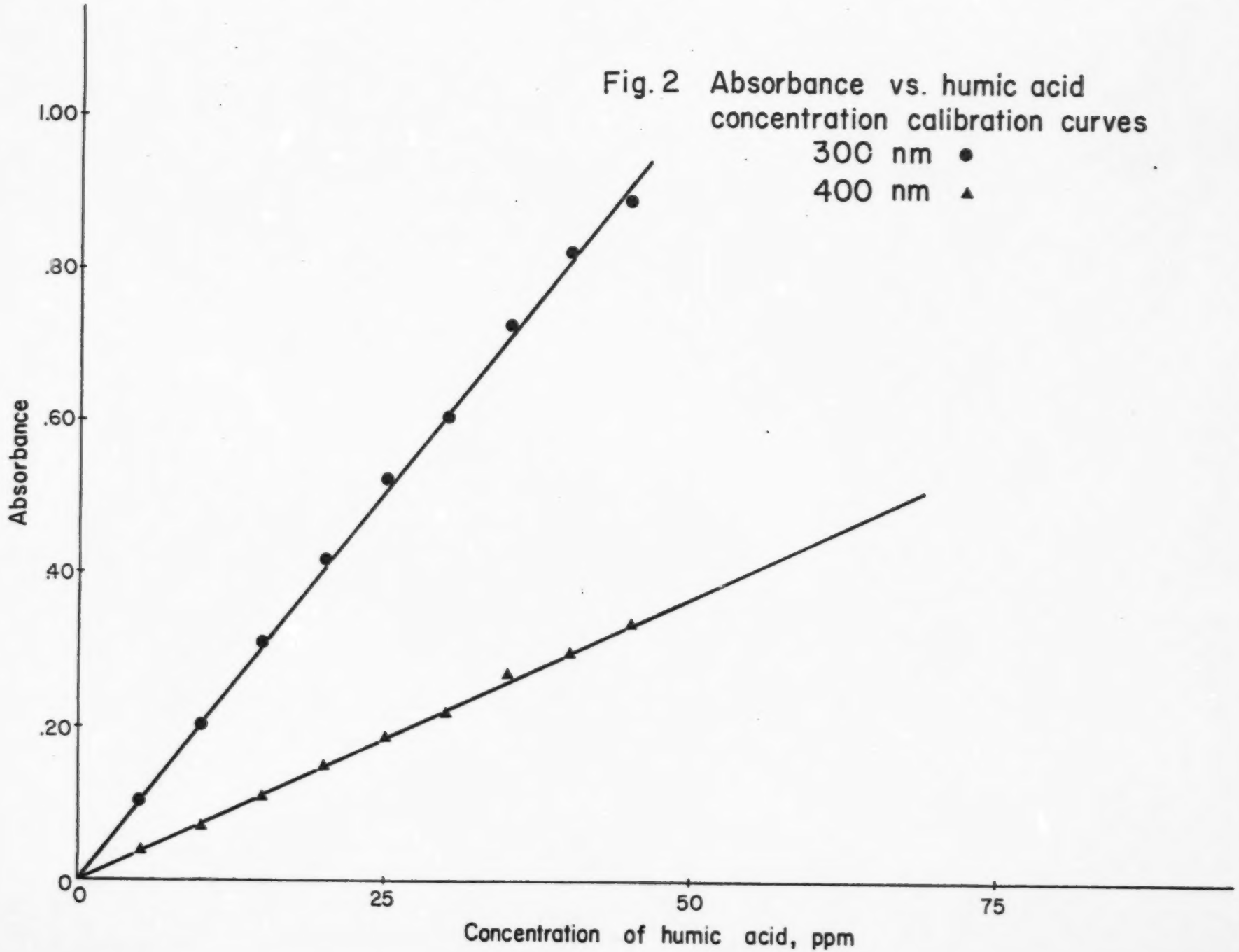
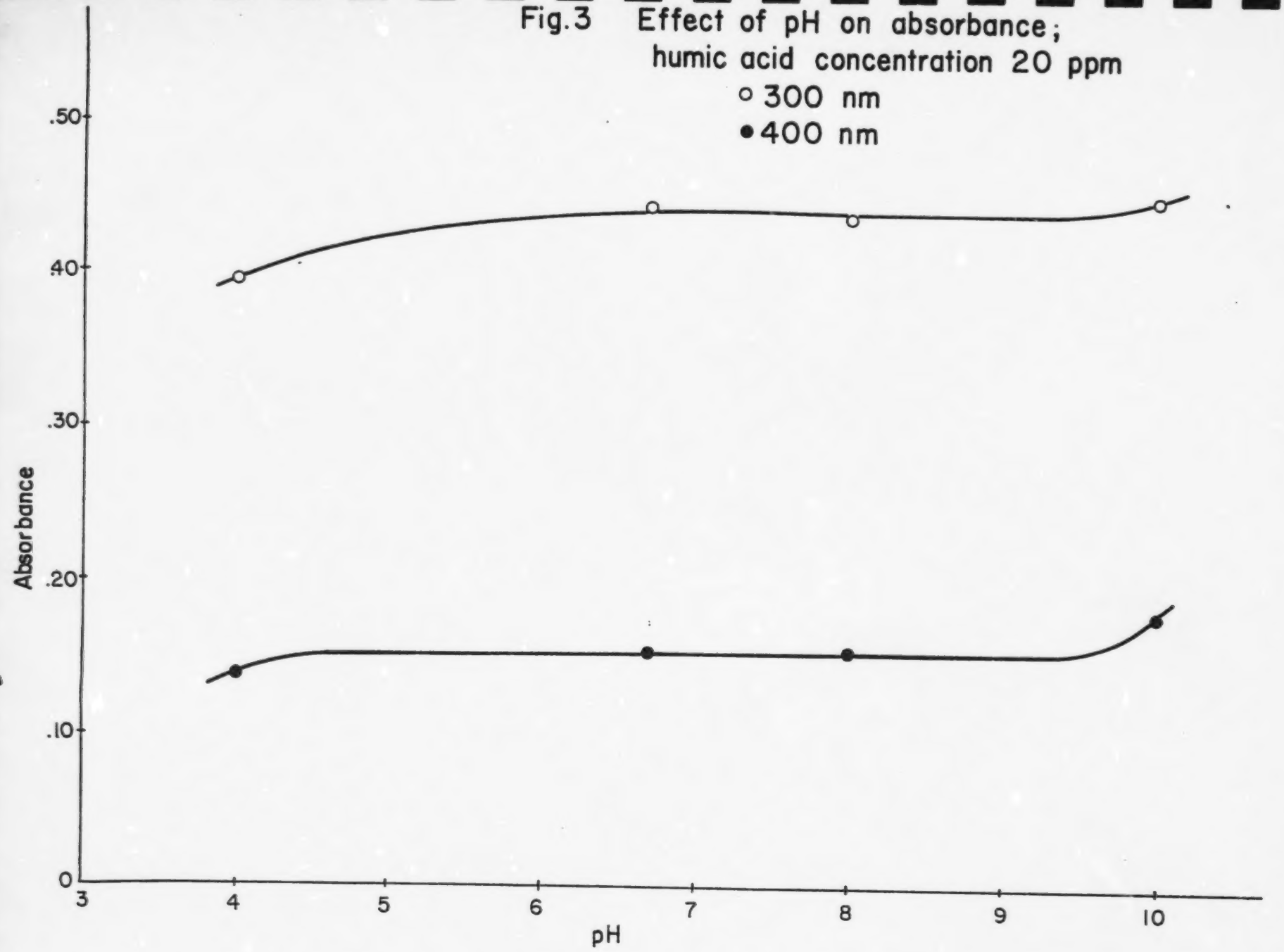


Fig. 2 Absorbance vs. humic acid concentration calibration curves
300 nm ●
400 nm ▲

Fig.3 Effect of pH on absorbance;
humic acid concentration 20 ppm
○ 300 nm
● 400 nm



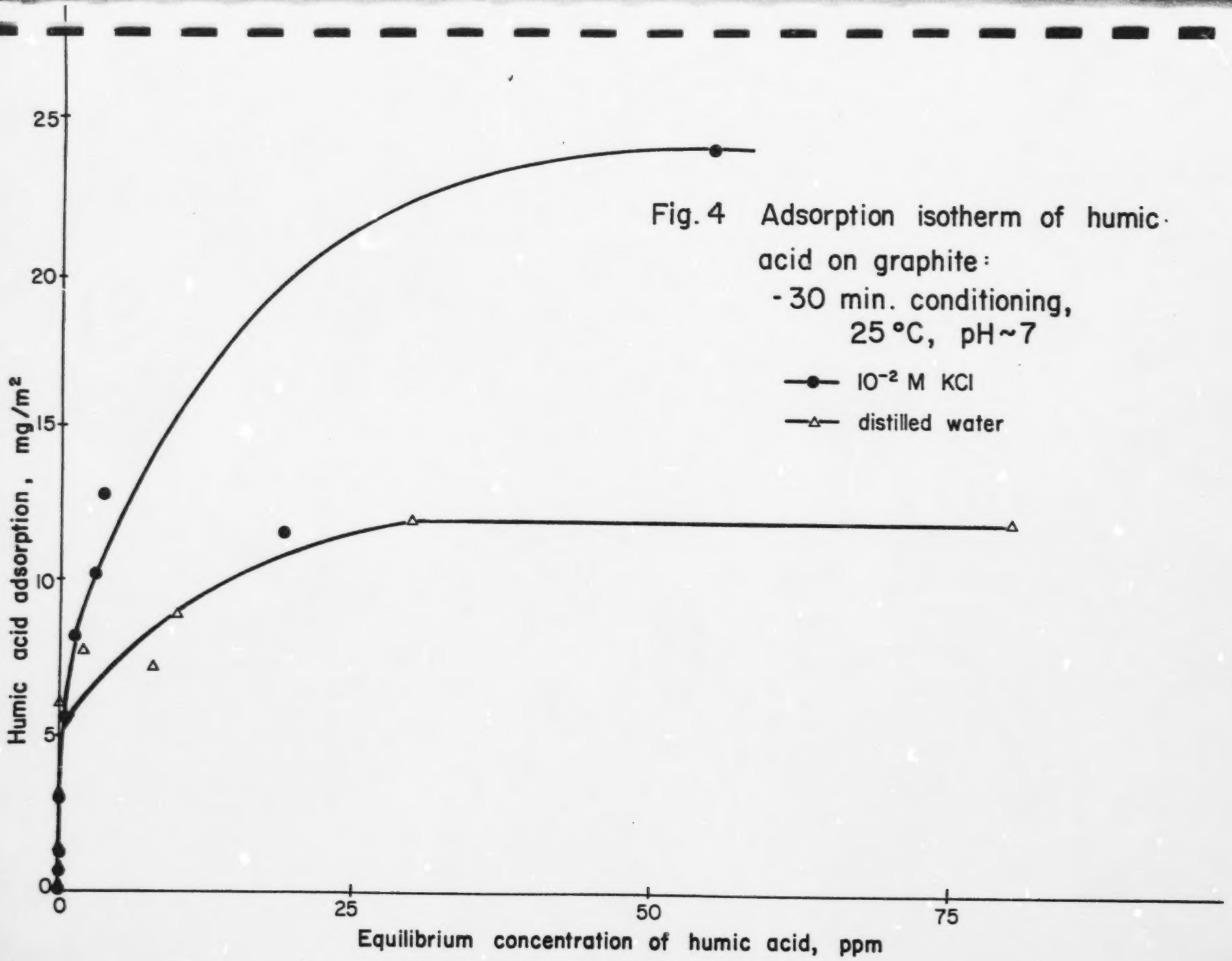


Fig. 4 Adsorption isotherm of humic acid on graphite:
- 30 min. conditioning,
25 °C, pH ~ 7

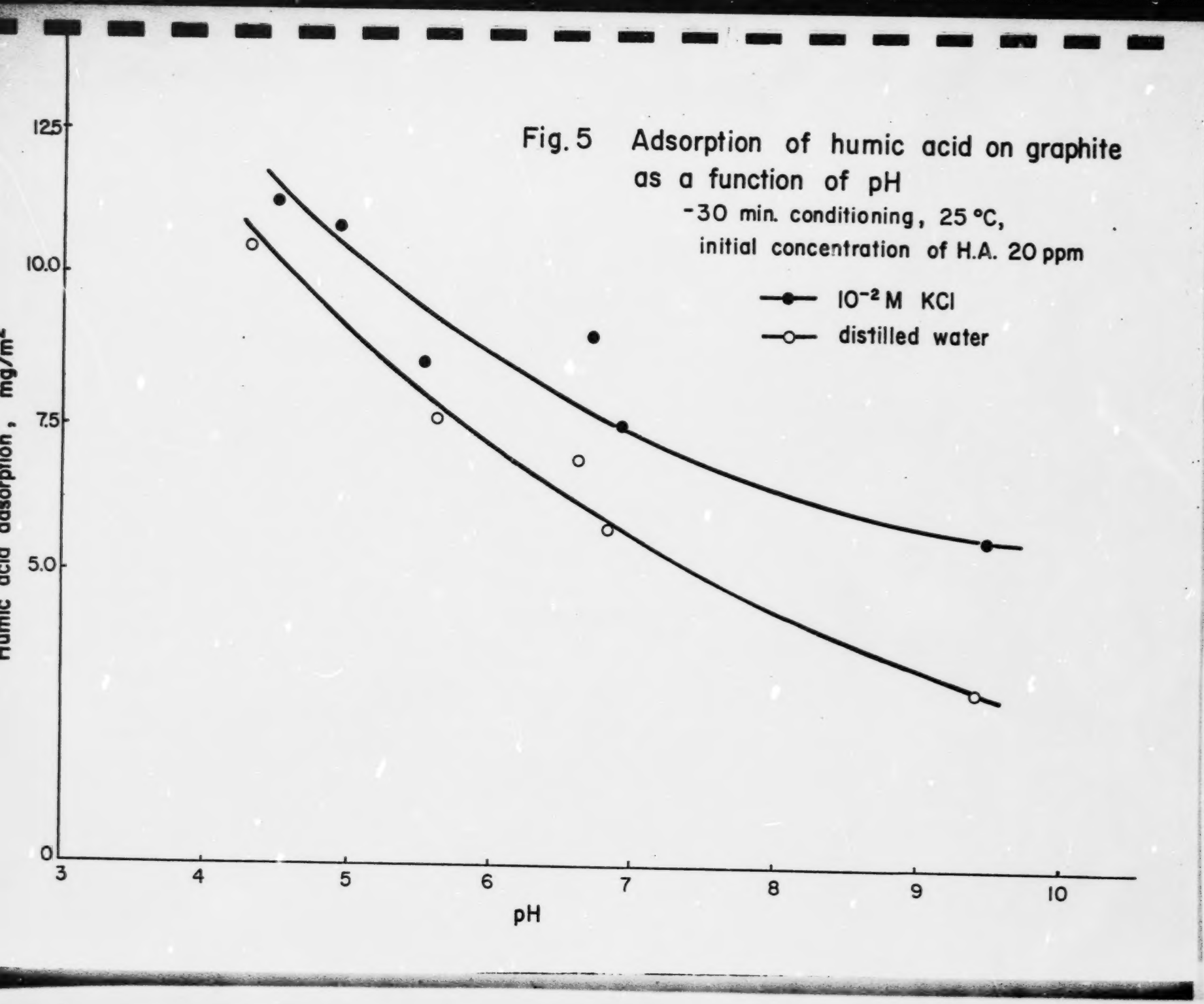


Fig. 5 Adsorption of humic acid on graphite as a function of pH
-30 min. conditioning, 25 °C,
initial concentration of H.A. 20 ppm
10⁻² M KCl
distilled water
Humic acid adsorption, mg/m²
12.5
10.0
7.5
5.0
0
3
4
5
6
7
8
9
10
pH

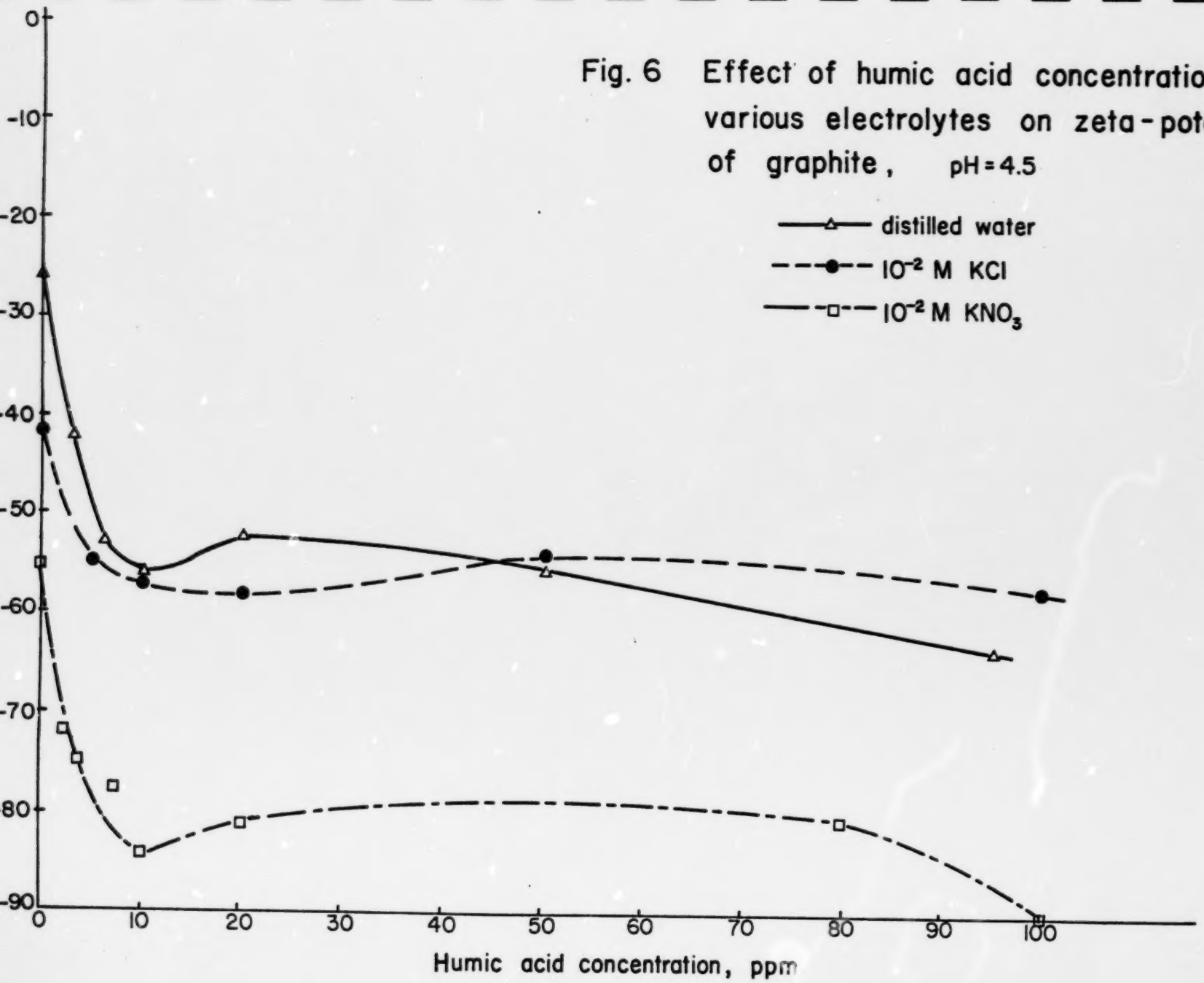


Fig. 6 Effect of humic acid concentration and various electrolytes on zeta-potential of graphite, pH = 4.5

Fig.7 Effect of humic acid and pH on zeta potential of graphite

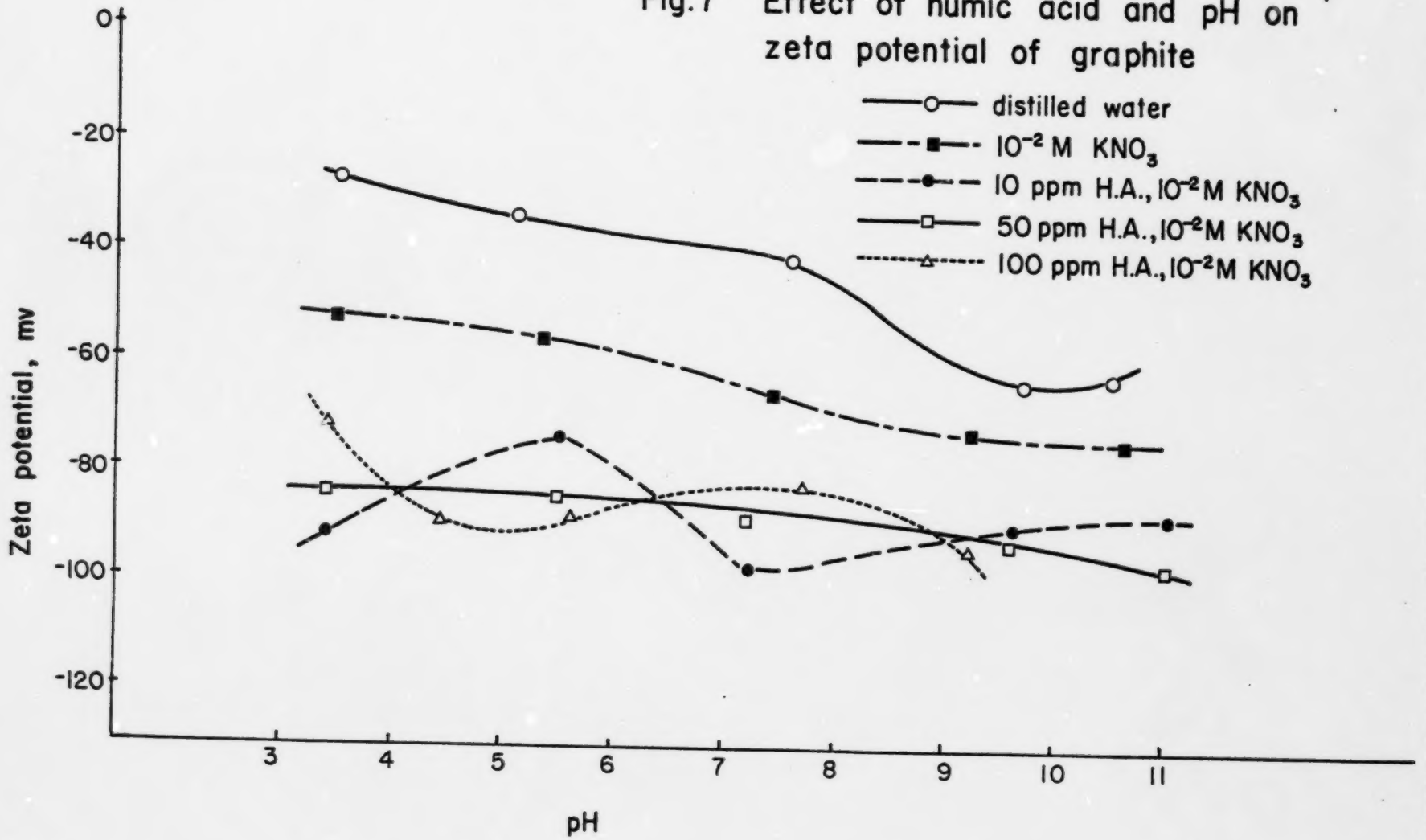
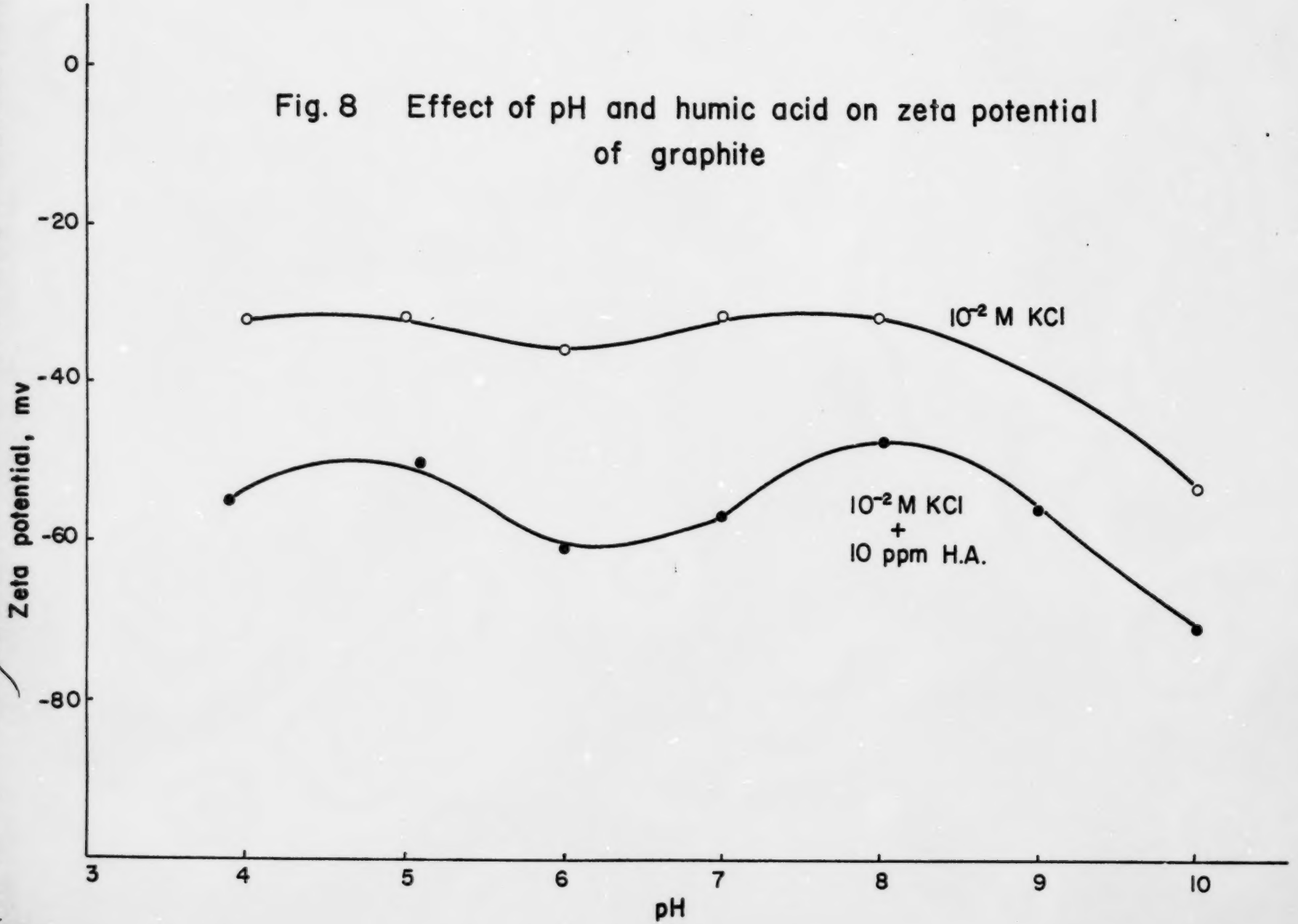


Fig. 8 Effect of pH and humic acid on zeta potential of graphite



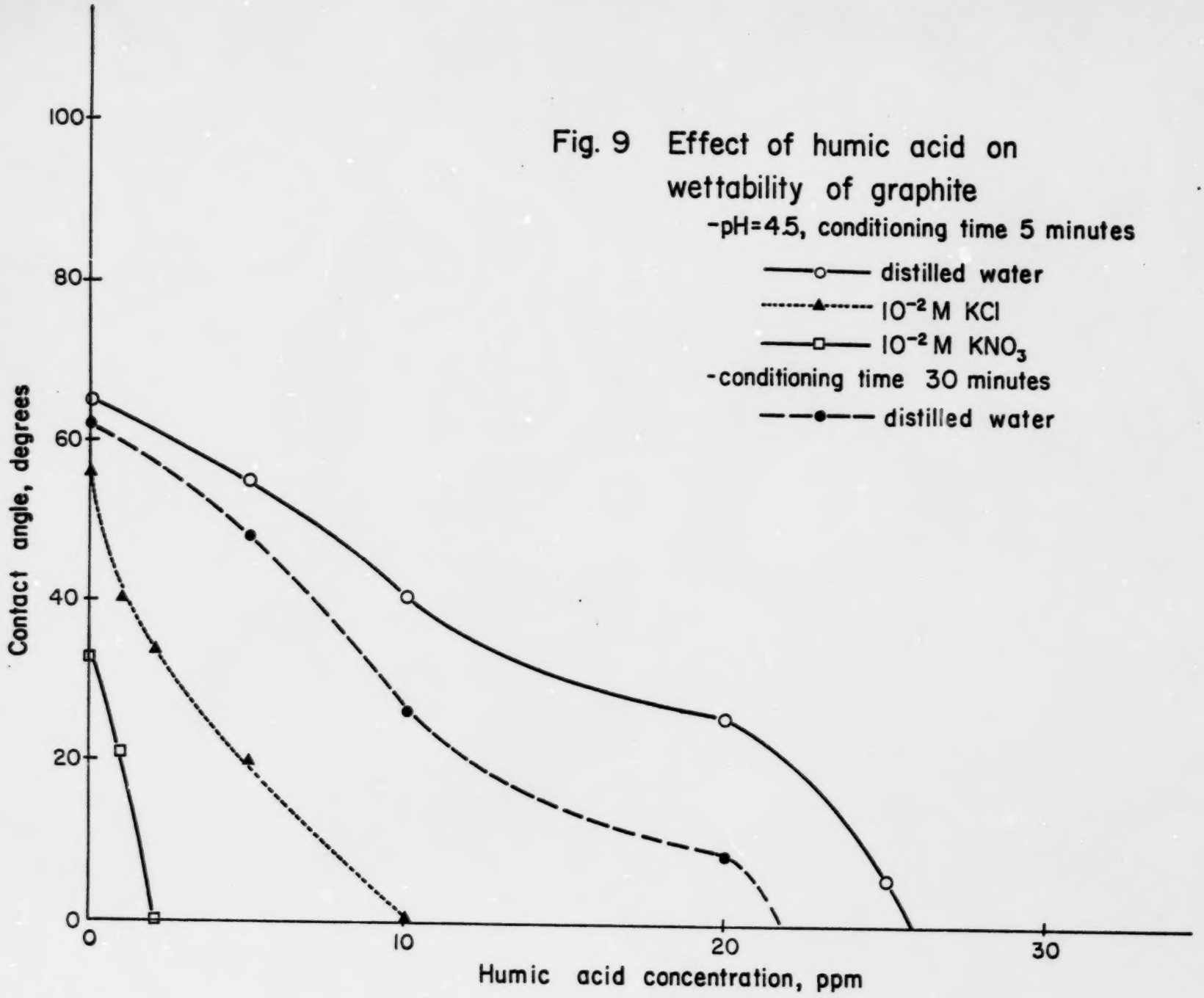
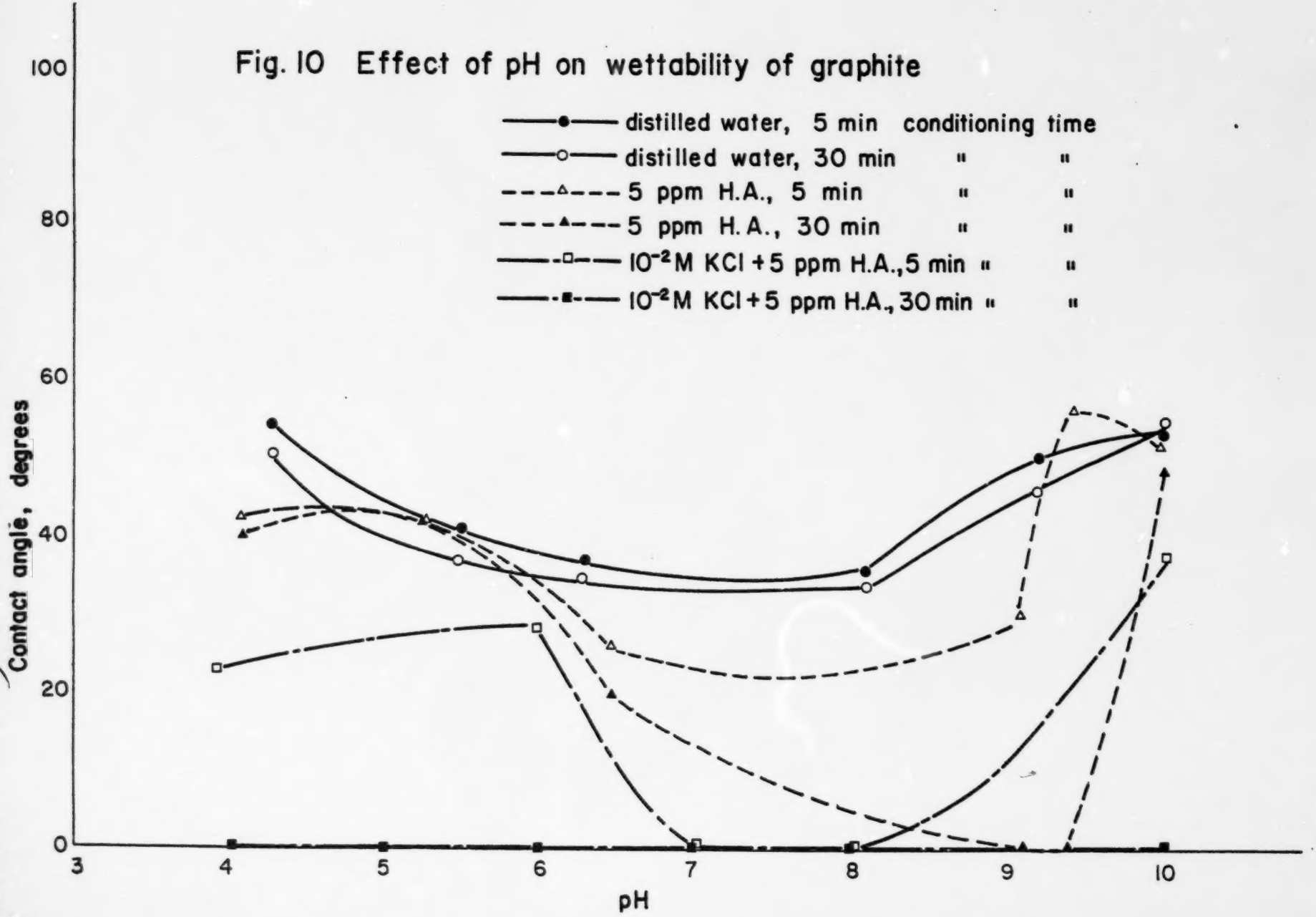


Fig. 9 Effect of humic acid on wettability of graphite
-pH=4.5, conditioning time 5 minutes
distilled water
10^{-2} M KCl
10^{-2} M KNO_3
-conditioning time 30 minutes
distilled water
Contact angle, degrees
100
80
60
40
20
0
0
10
20
30
Humic acid concentration, ppm

Fig. 10 Effect of pH on wettability of graphite



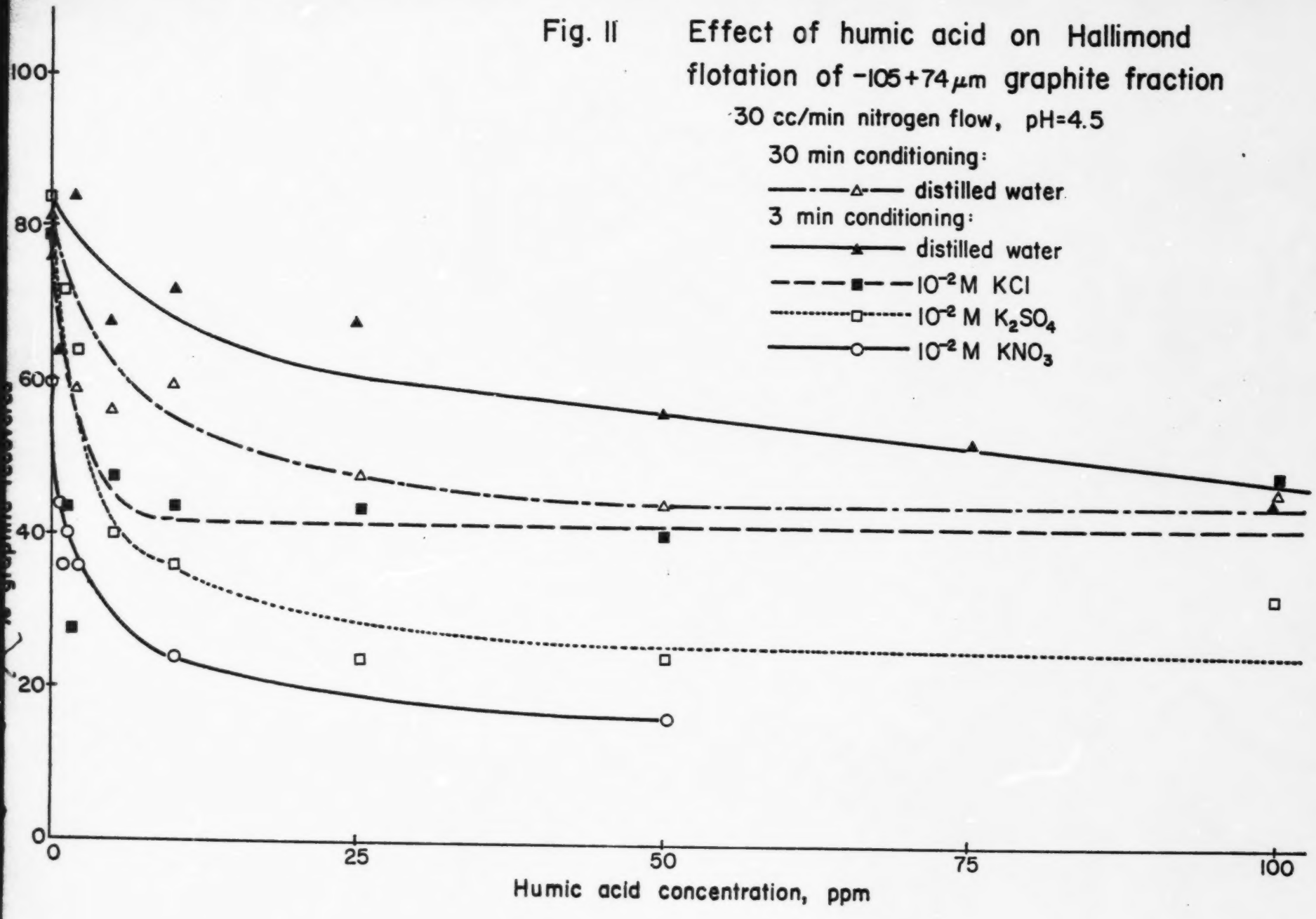
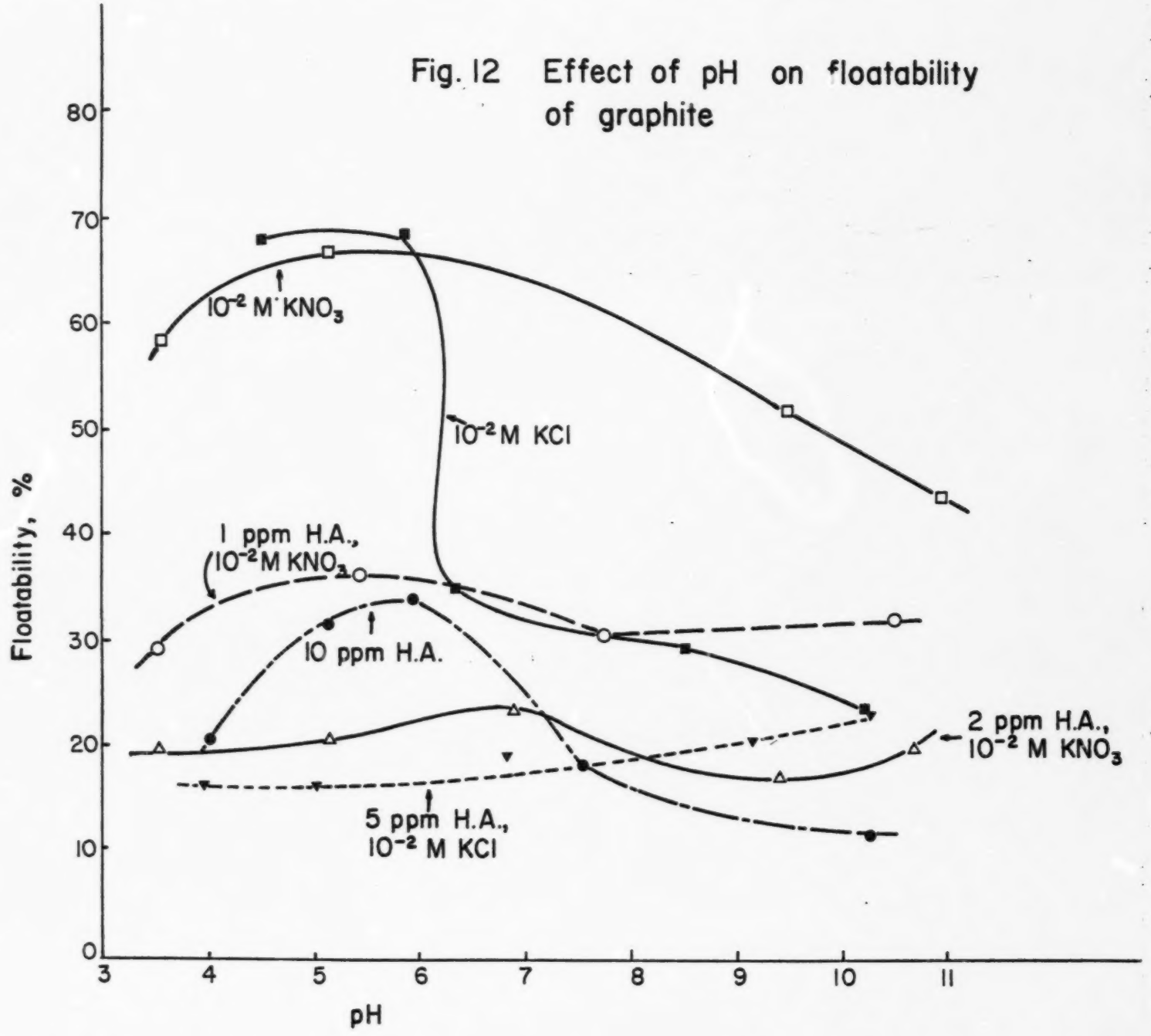


Fig. II Effect of humic acid on Hallimond flotation of -105+74 μm graphite fraction
30 cc/min nitrogen flow, pH=4.5
30 min conditioning:
distilled water
3 min conditioning:
distilled water
10⁻² M KCl
10⁻² M K₂SO₄
10⁻² M KNO₃
100
80
60
40
20
0
0
25
50
75
100
Humic acid concentration, ppm

Fig. 12 Effect of pH on floatability of graphite



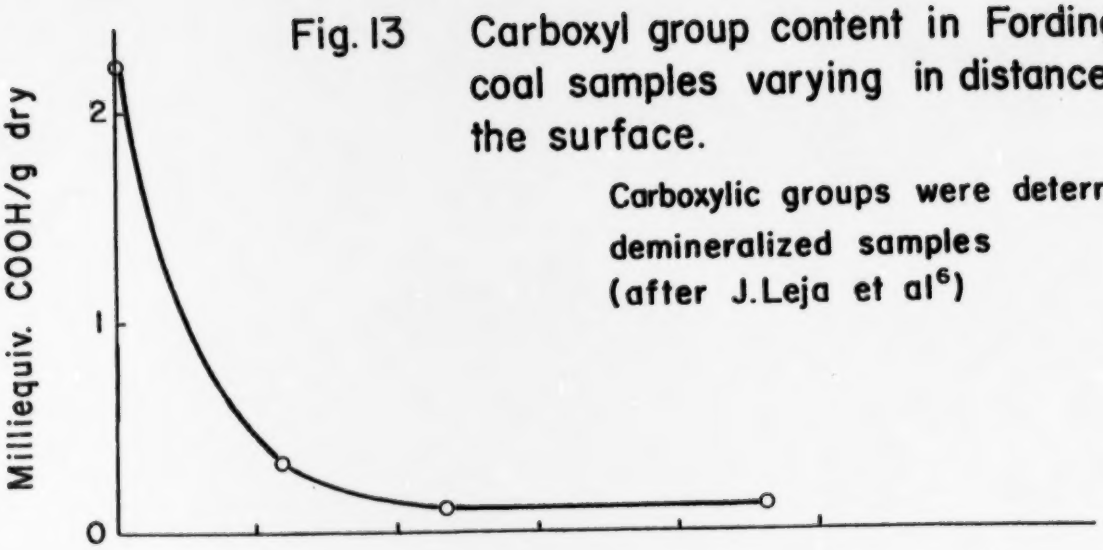


Fig. 13 Carboxyl group content in Fording River coal samples varying in distance from the surface.

Carboxylic groups were determined in demineralized samples (after J.Leja et al[6])

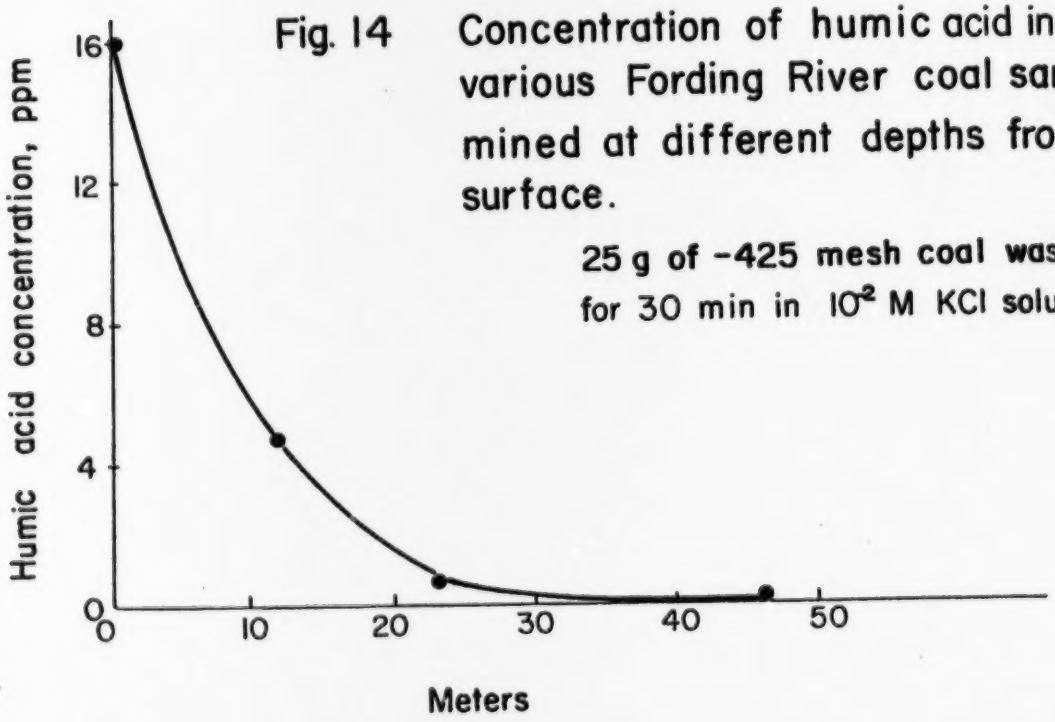


Fig. 14 Concentration of humic acid in the pulp of various Fording River coal samples mined at different depths from the surface.

25 g of -425 mesh coal was conditioned for 30 min in 10^{-2} M KCl solution, pH 4.5

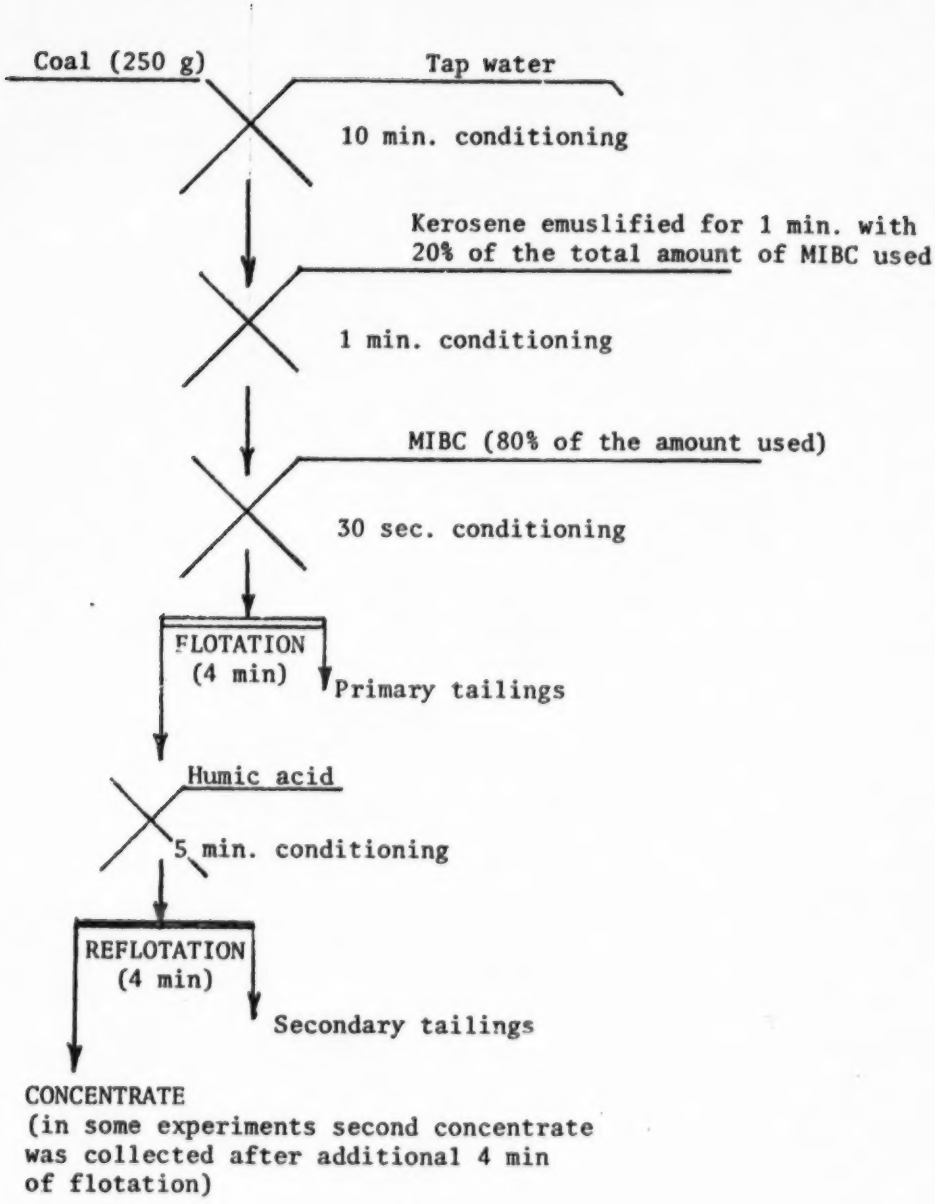

Coal (250 g)
Tap water
10 min. conditioning
Kerosene emuslified for 1 min. with 20% of the total amount of MIBC used
1 min. conditioning
MIBC (80% of the amount used)
30 sec. conditioning
FLOTATION (4 min)
Primary tailings
Humic acid
5 min. conditioning
REFLOTATION (4 min)
Secondary tailings
CONCENTRATE
(in some experiments second concentrate was collected after additional 4 min of flotation)

Fig. 15. Schematic illustration of the batch flotation experiments procedure

Fig. 16 Effect of KCl concentration on zeta potential of Fording River coal (45.7 m)

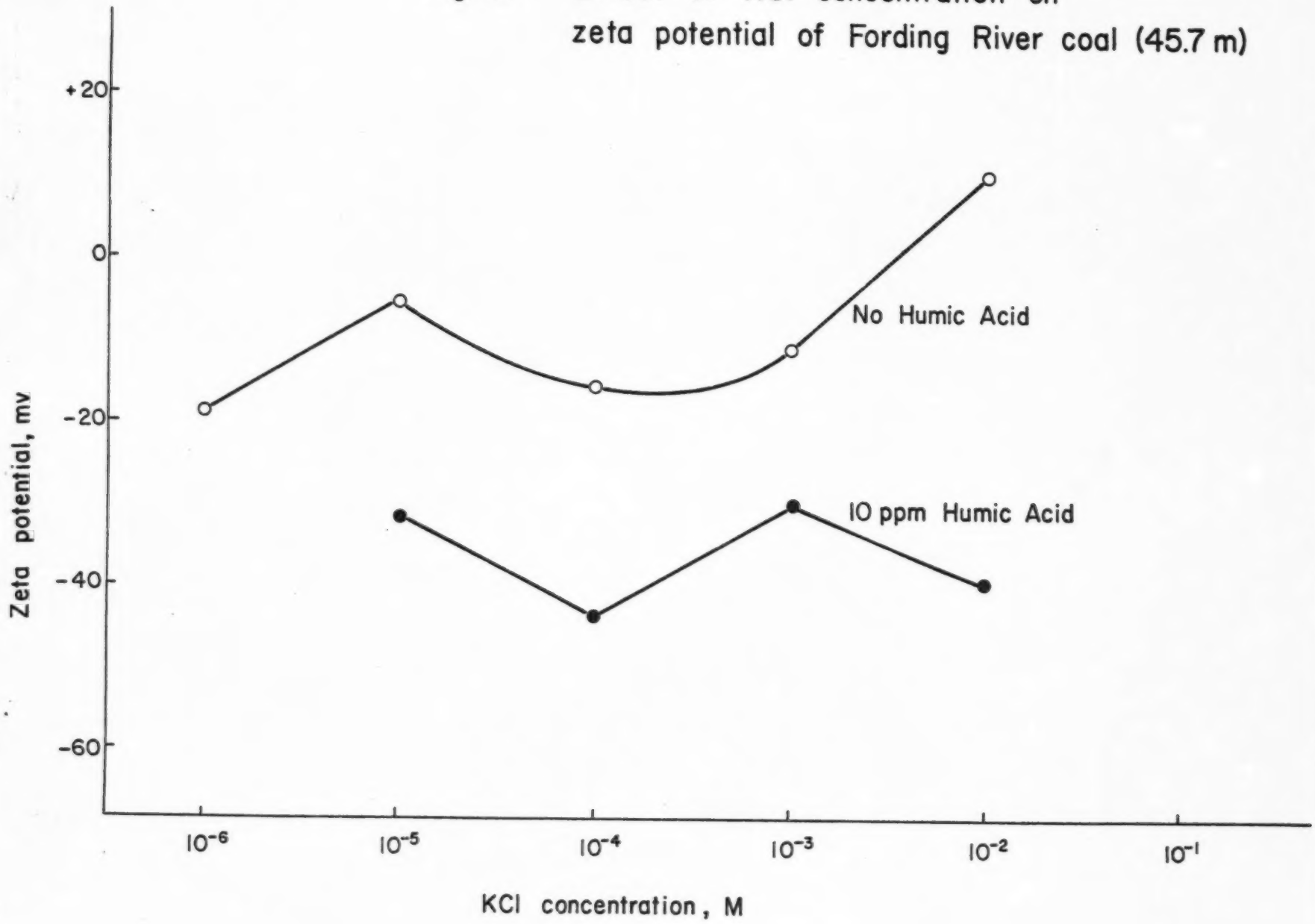


Fig. 17 Effect of humic acid on zeta potential of Fording River coal (45.7 m)

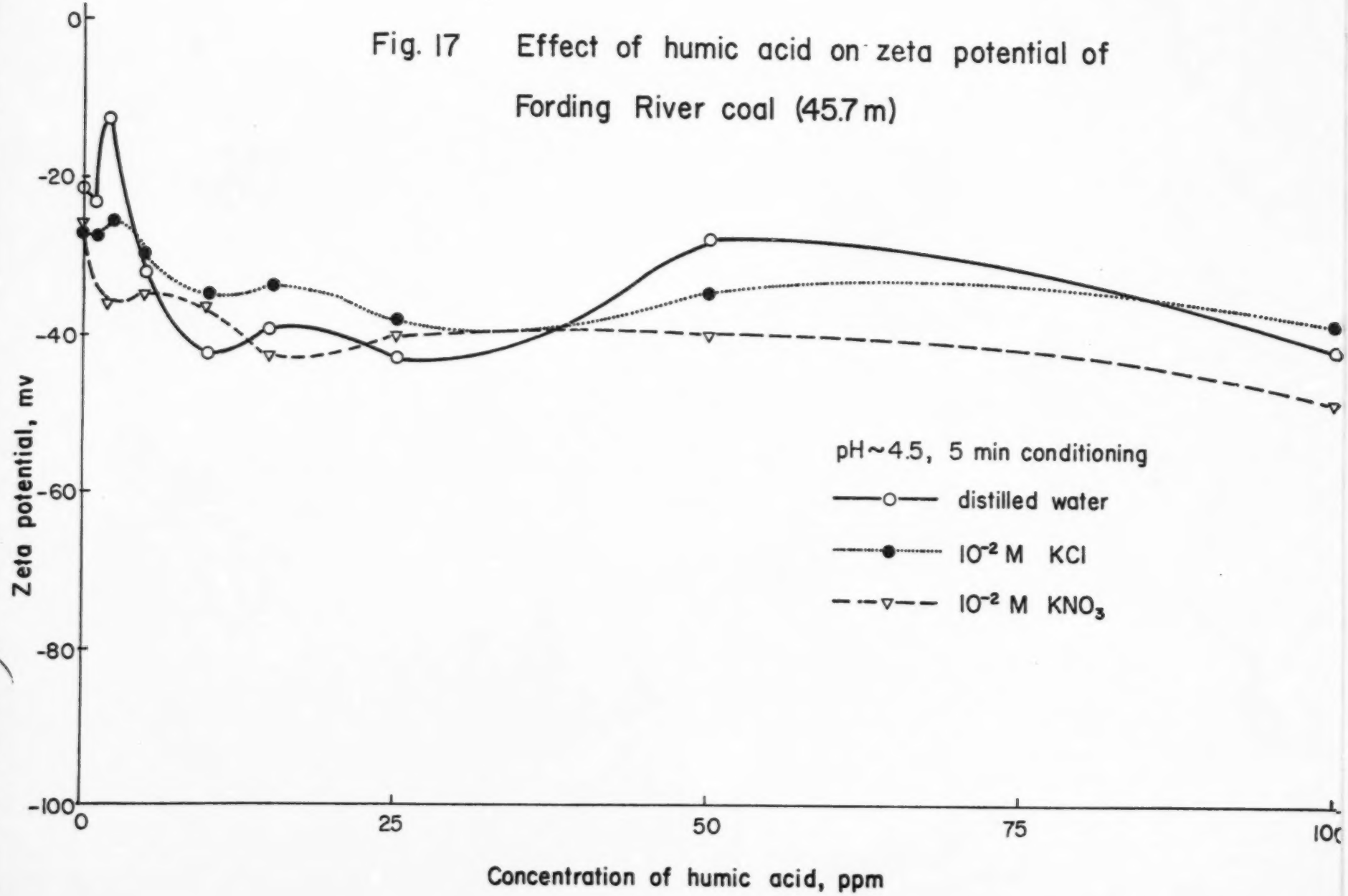


Fig. 18 Effect of pH on zeta potential of Fording River coal (45.7m)

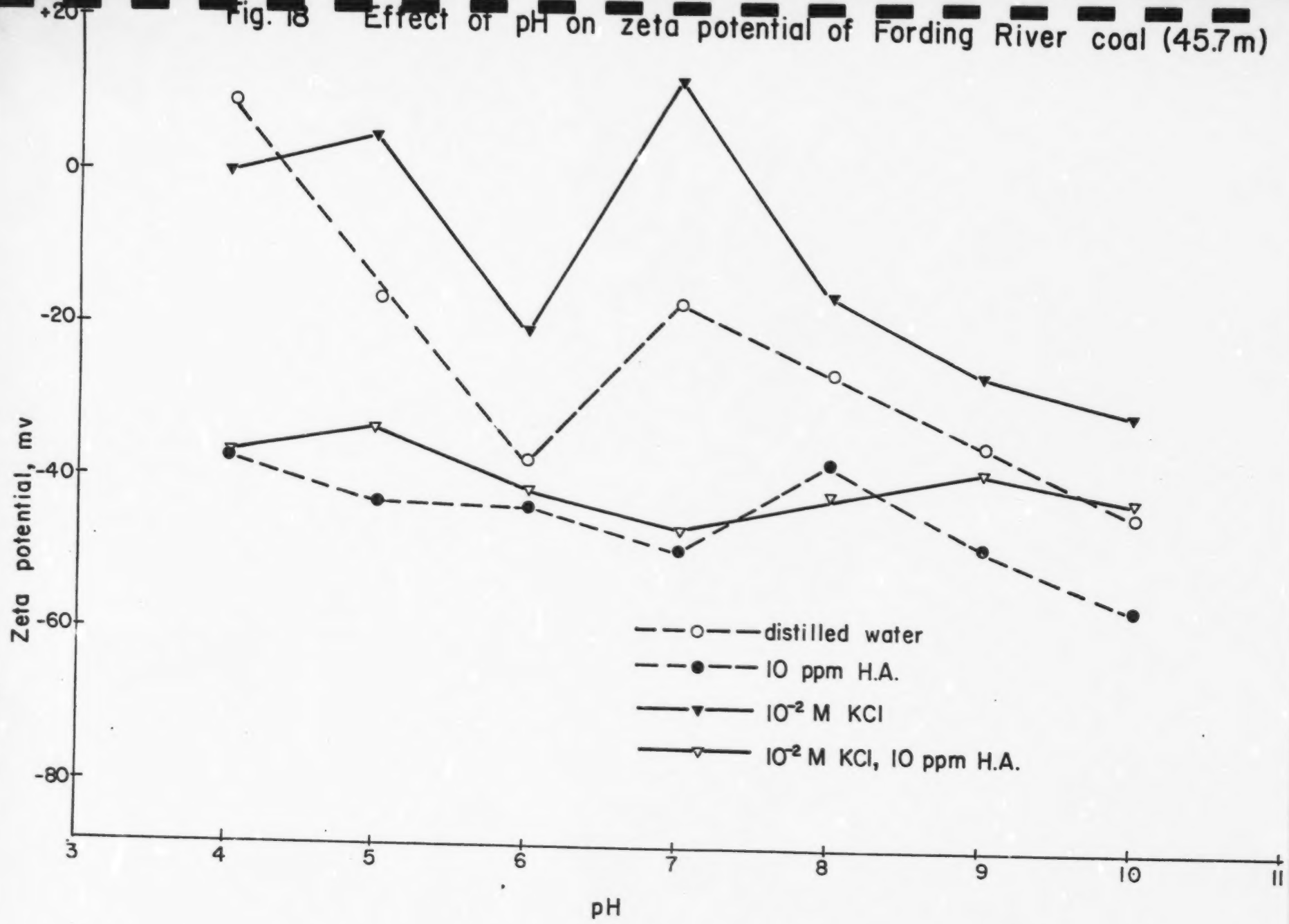


Fig. 19 Effect of humic acid and conditioning time on Hallimond flotation of -100+230 mesh Fording River coal (45.7 m)

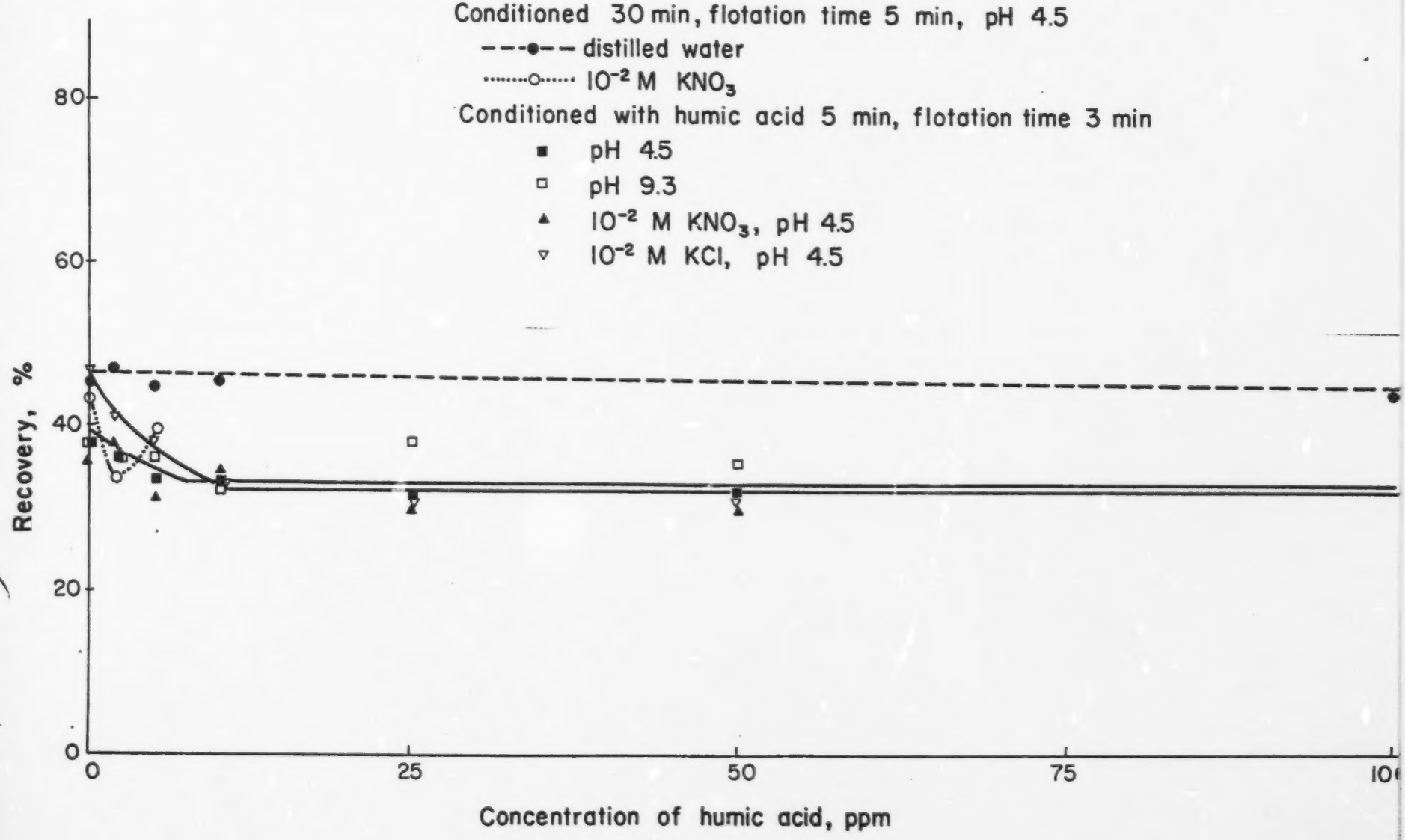


Fig. 20 Flotation kinetics of Fording River coal (45.7m)

Coal was first conditioned for 25 min with 0.0028 g/l MIBC, pH 4.5, and then for 5 min with humic acid.

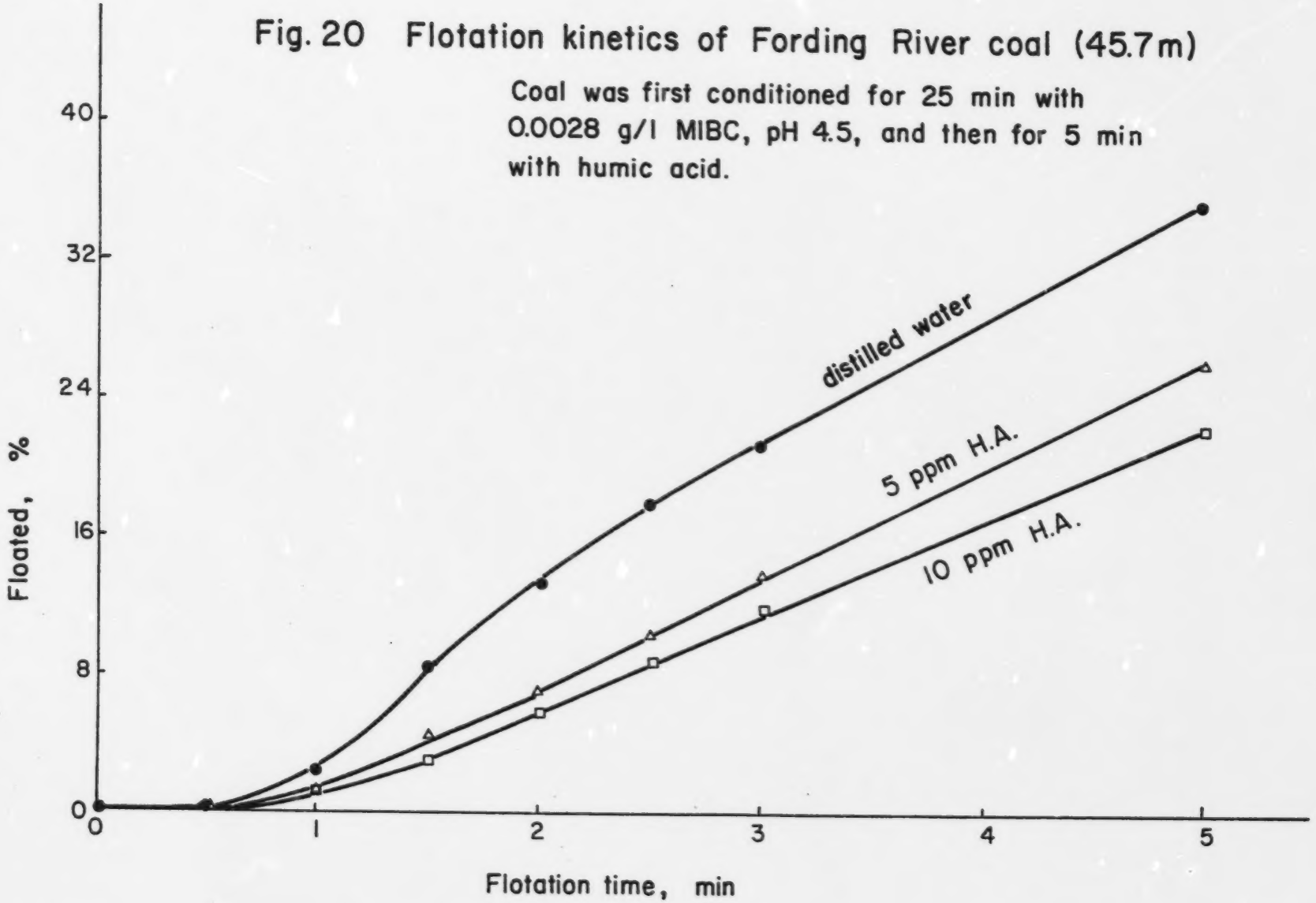


Fig. 21 Adsorption isotherm of humic acid on −106 + 53 μm coal-pyrite

Conditioned 30 min at 25 °C, pH~7

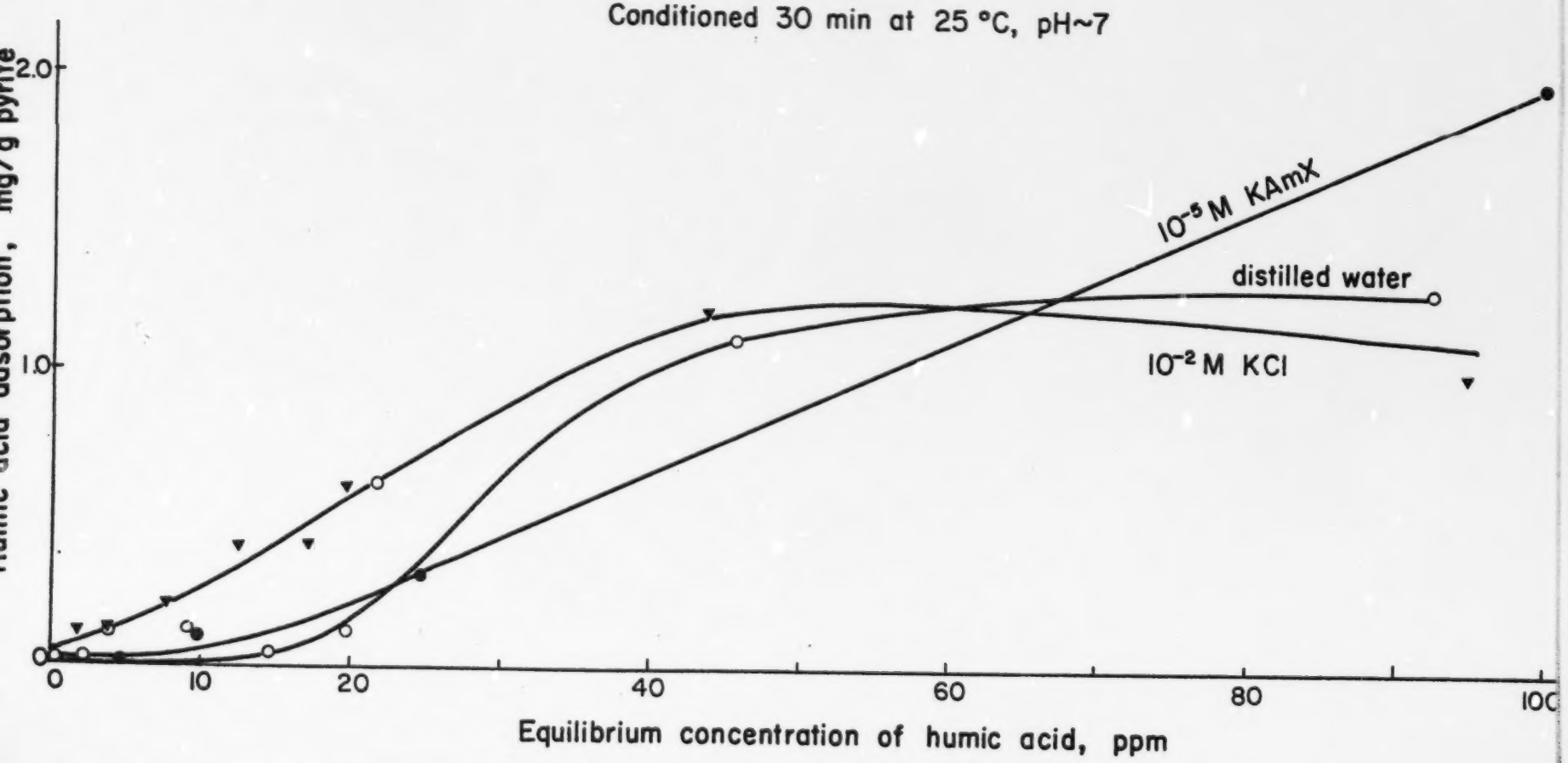


Fig. 22 Effect of humic acid on floatability of coal-pyrite

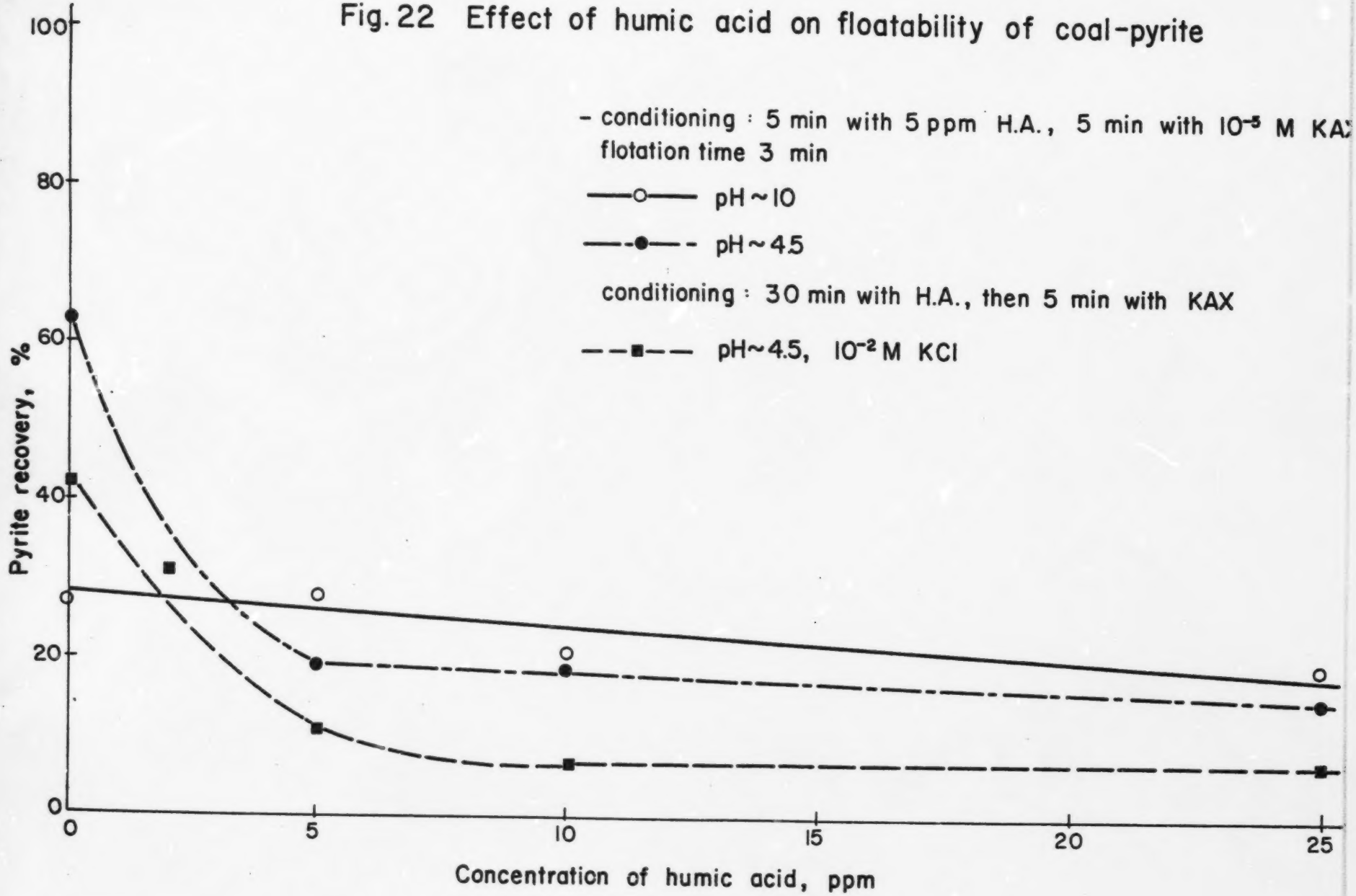


Fig. 23 Hallimond flotation of coal pyrite vs. pH

30 cc/min N_2 ; flotation time 3 min.
conditioning time 5 min.

—○— 10^{-5} M KAmX

– –●– – (i) 5 ppm H.A.; (ii) 10^{-5} M KAmX

—△— (i) 10^{-5} M KAmX (ii) 5 ppm H.A.

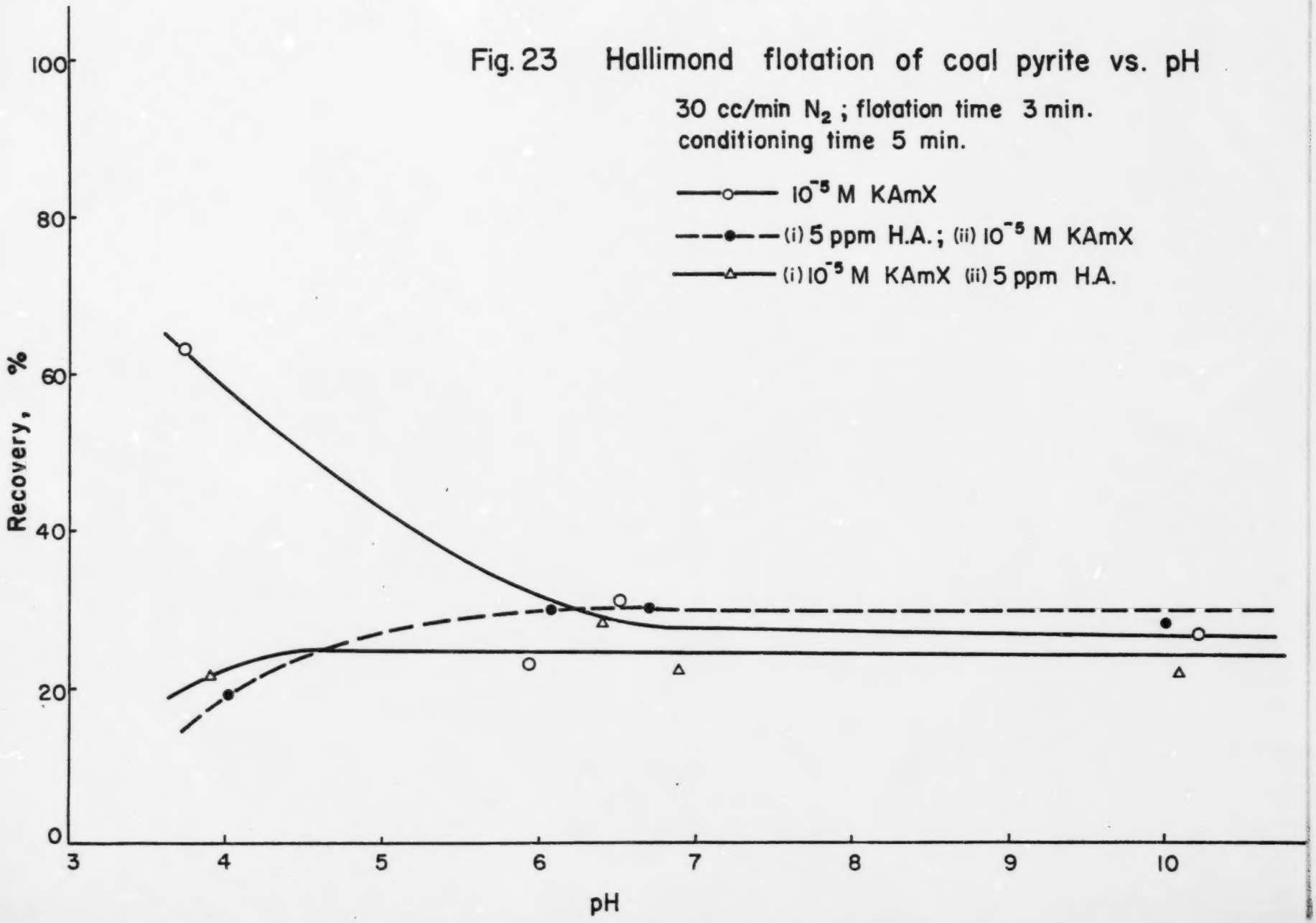


Fig. 24. Hallimond flotation of pyrite vs. pH

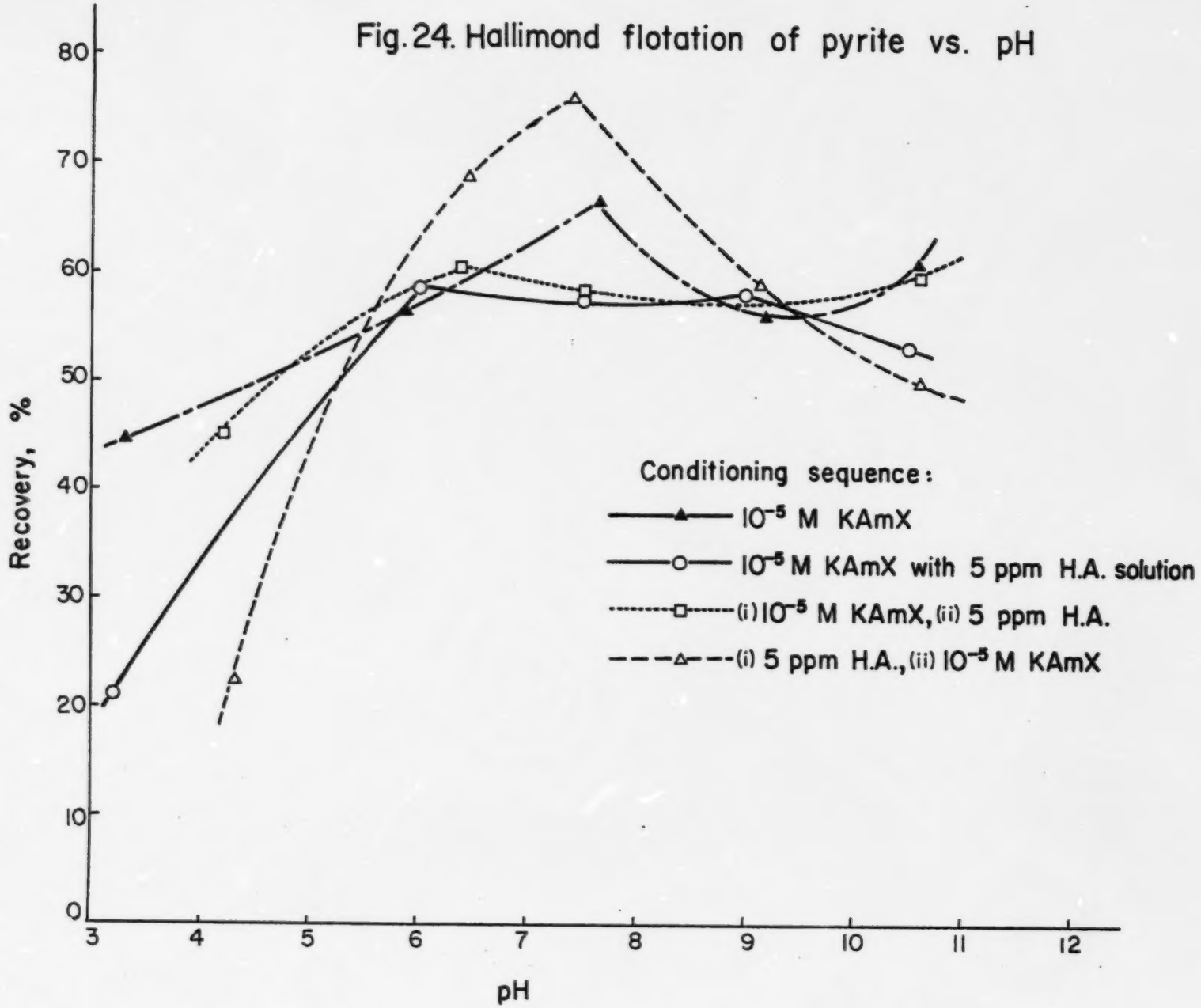


Fig. 25 Effect of humic acid on flotation kinetics of coal-pyrite

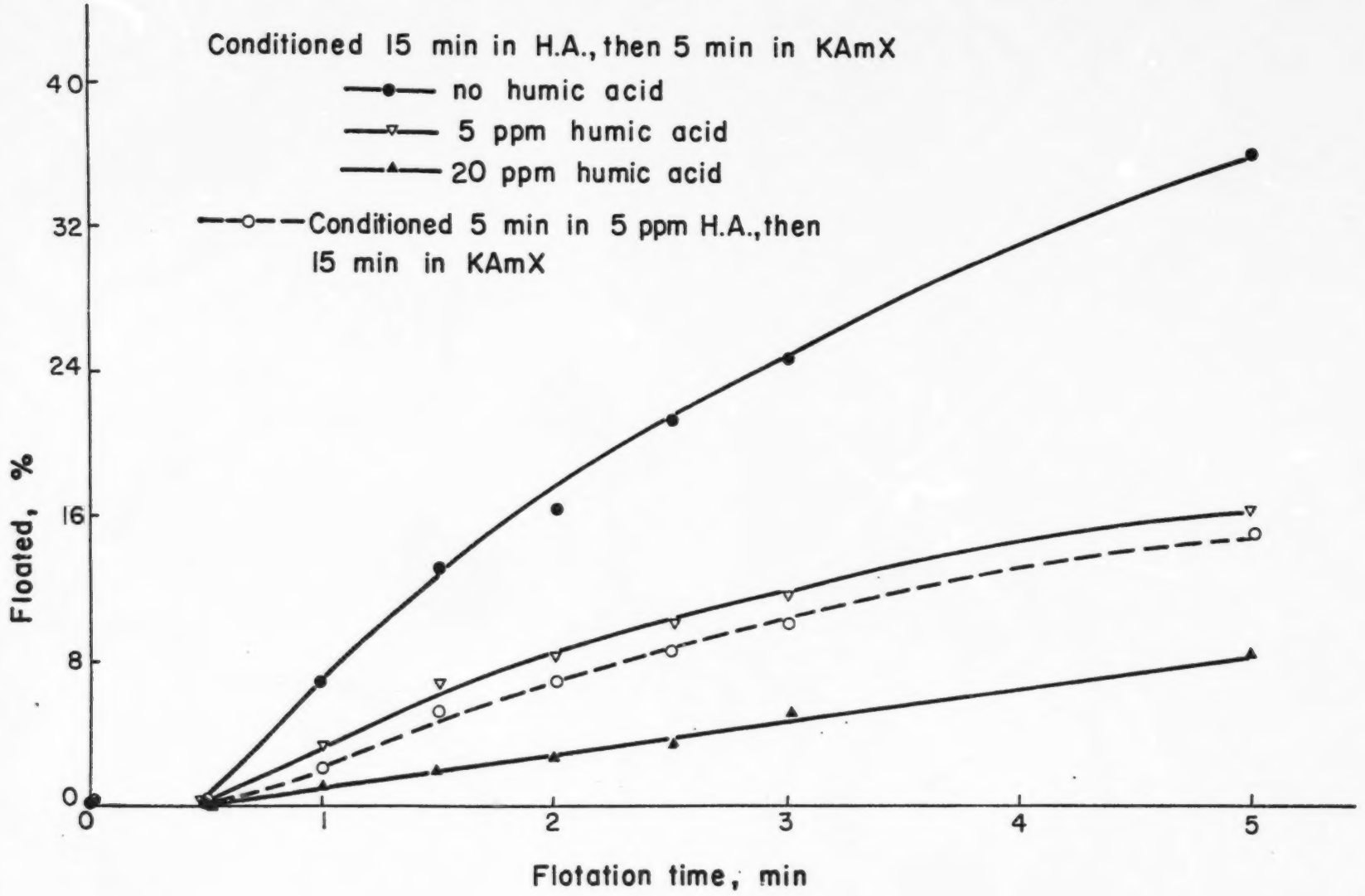


Fig. 26 Effect of humic acid on cleaning flotation of Fording River coal (45.7, 22.9, 11.6 m)

Conditioning 10 min, then 1 min with 960 g/t emulsified kerosene and 30 sec with 80 g/t MIBC. Flotation time 4 min.

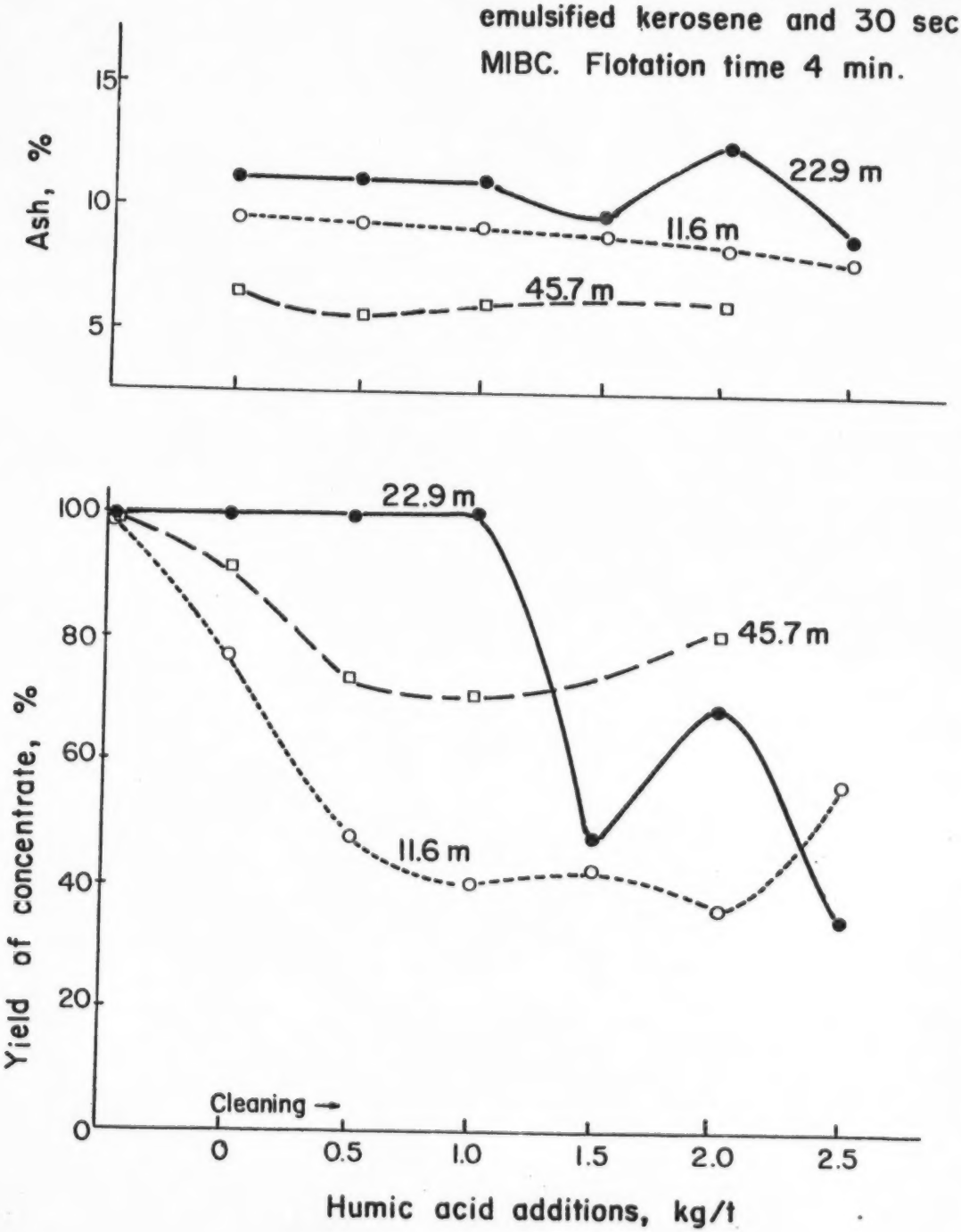


Fig. 27. Effect of humic acid on cleaning flotation of Fording River coal (45.7 m)

Conditioning 10 min, then 1 min with 960 g/t emulsified kerosene and 30 sec. with 80 g/t MIBC. Flotation time 4 min.

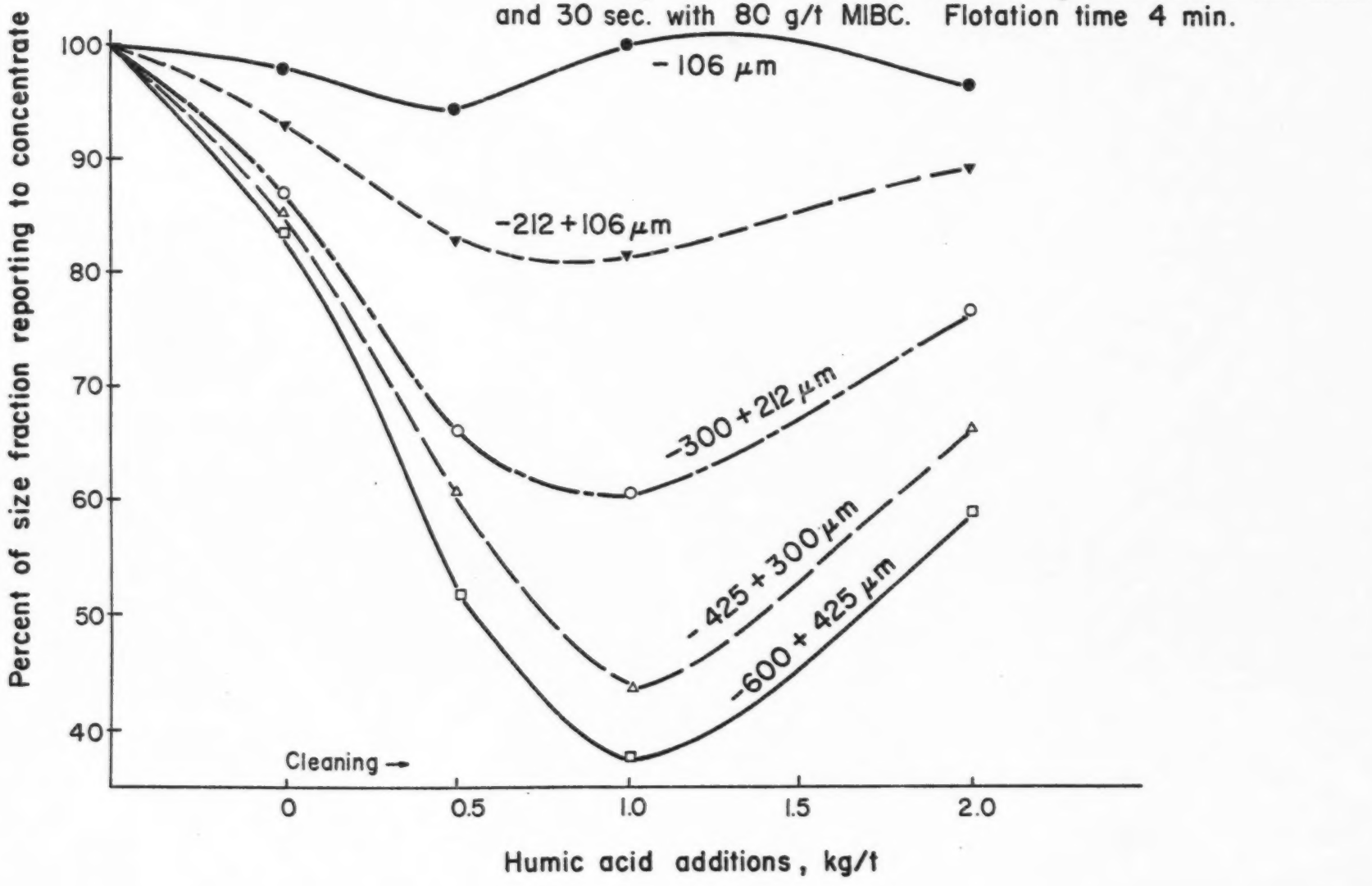


Fig. 28. Effect of humic acid on cleaning flotation of Fording River coal (22.9 m)

Conditioning 10 min, then 1 min with 960 g/t emulsified kerosene and 30 sec with 80 g/t MIBC.
Flotation time 4 min.

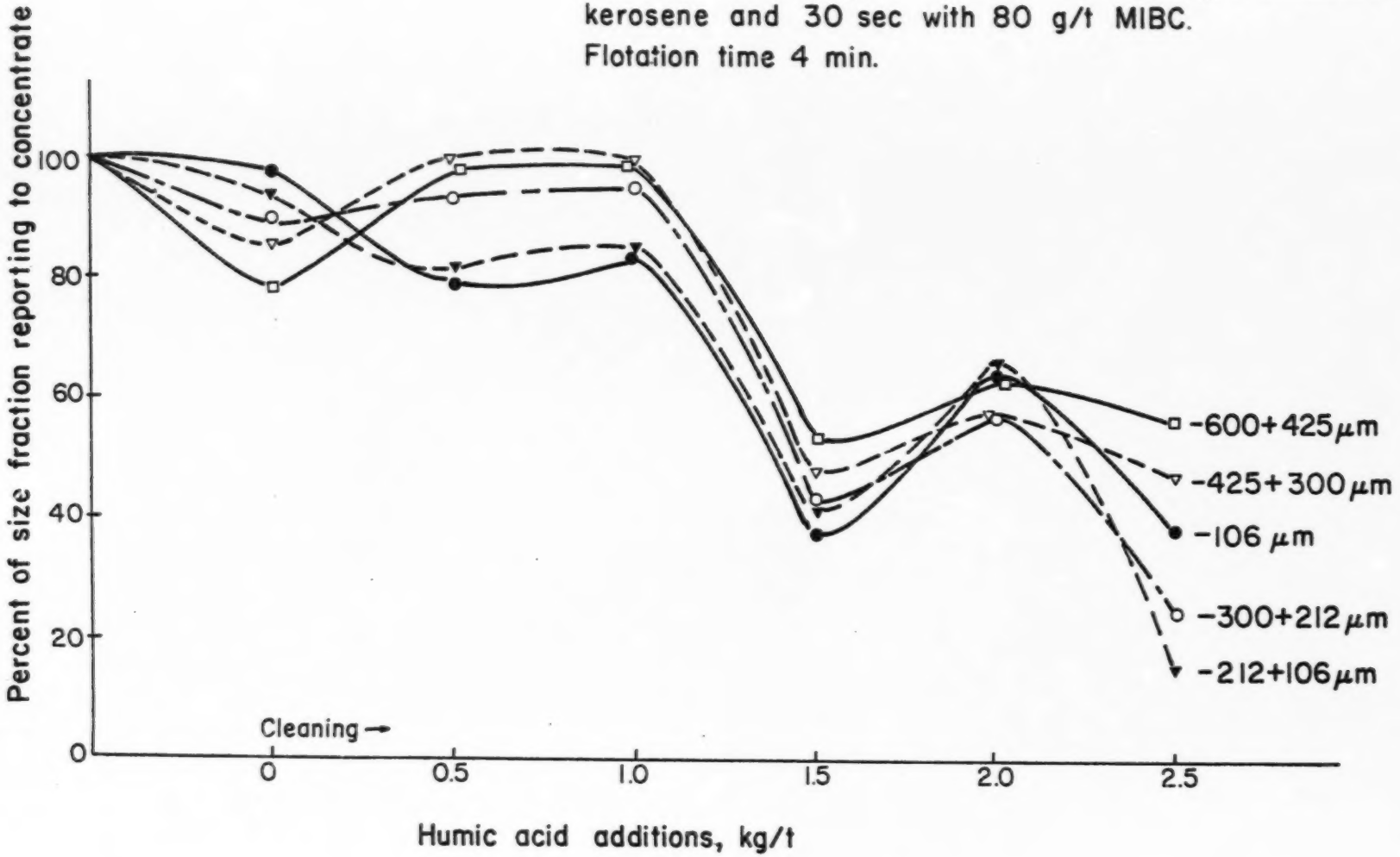


Fig. 29. Effect of humic acid on cleaning flotation of Fording River coal (11.6 m)

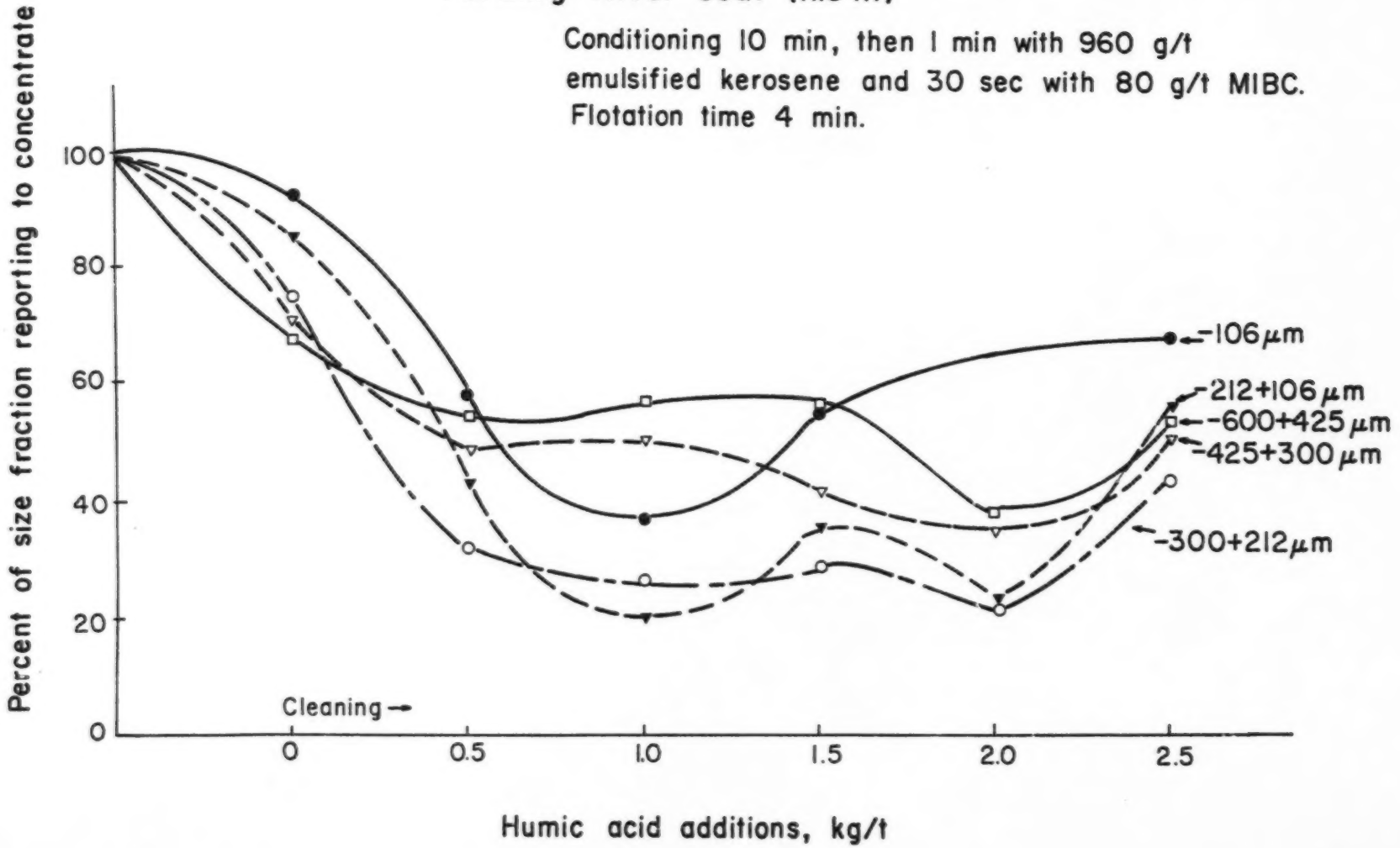


Fig. 30 Effect of humic acid on cleaning flotation of low sulphur DEVCO coal

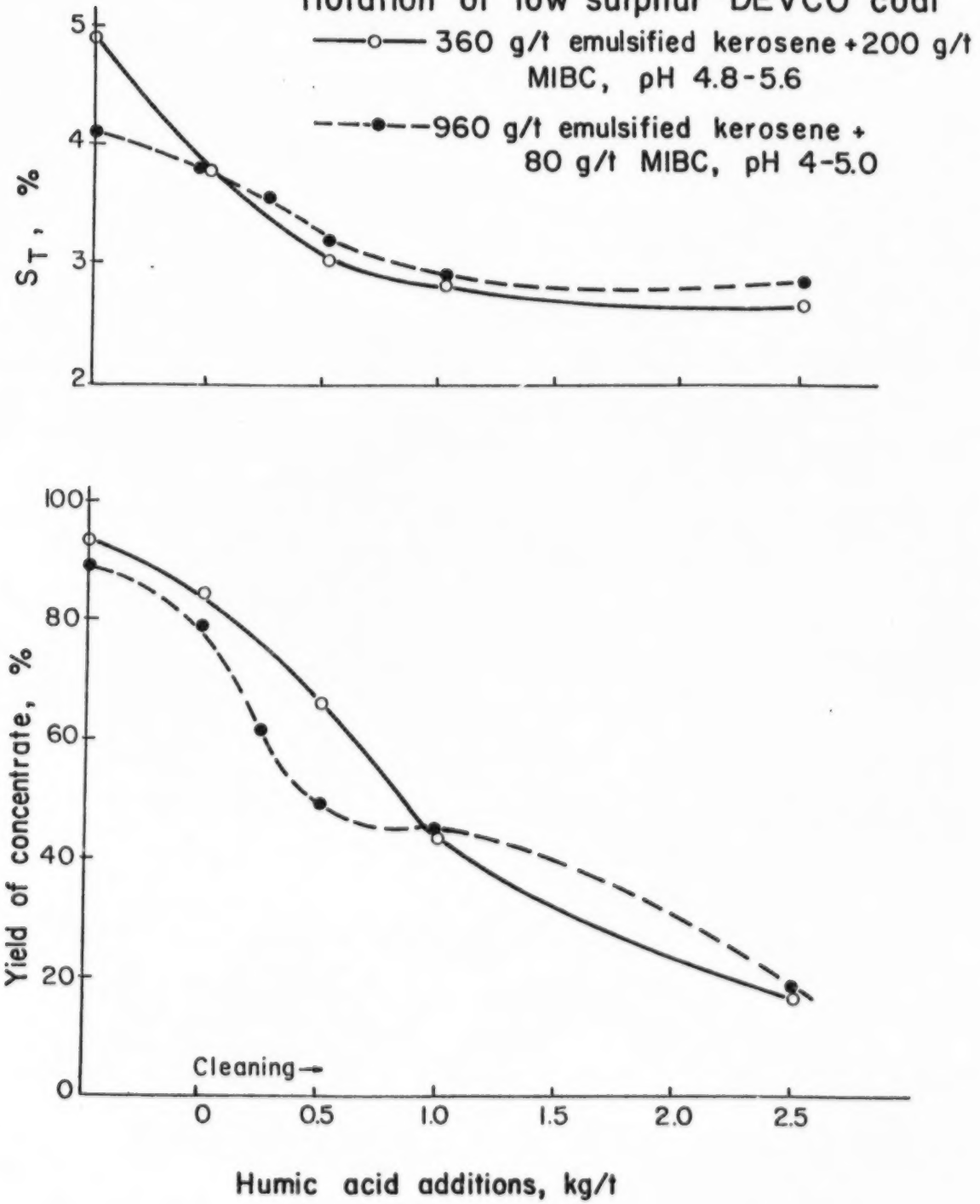


Fig. 31 Effect of humic acid on cleaning flotation of high sulphur DEVCO coal

960 g/t emulsified kerosene + 80 g/t MIBC, pH ~5.5

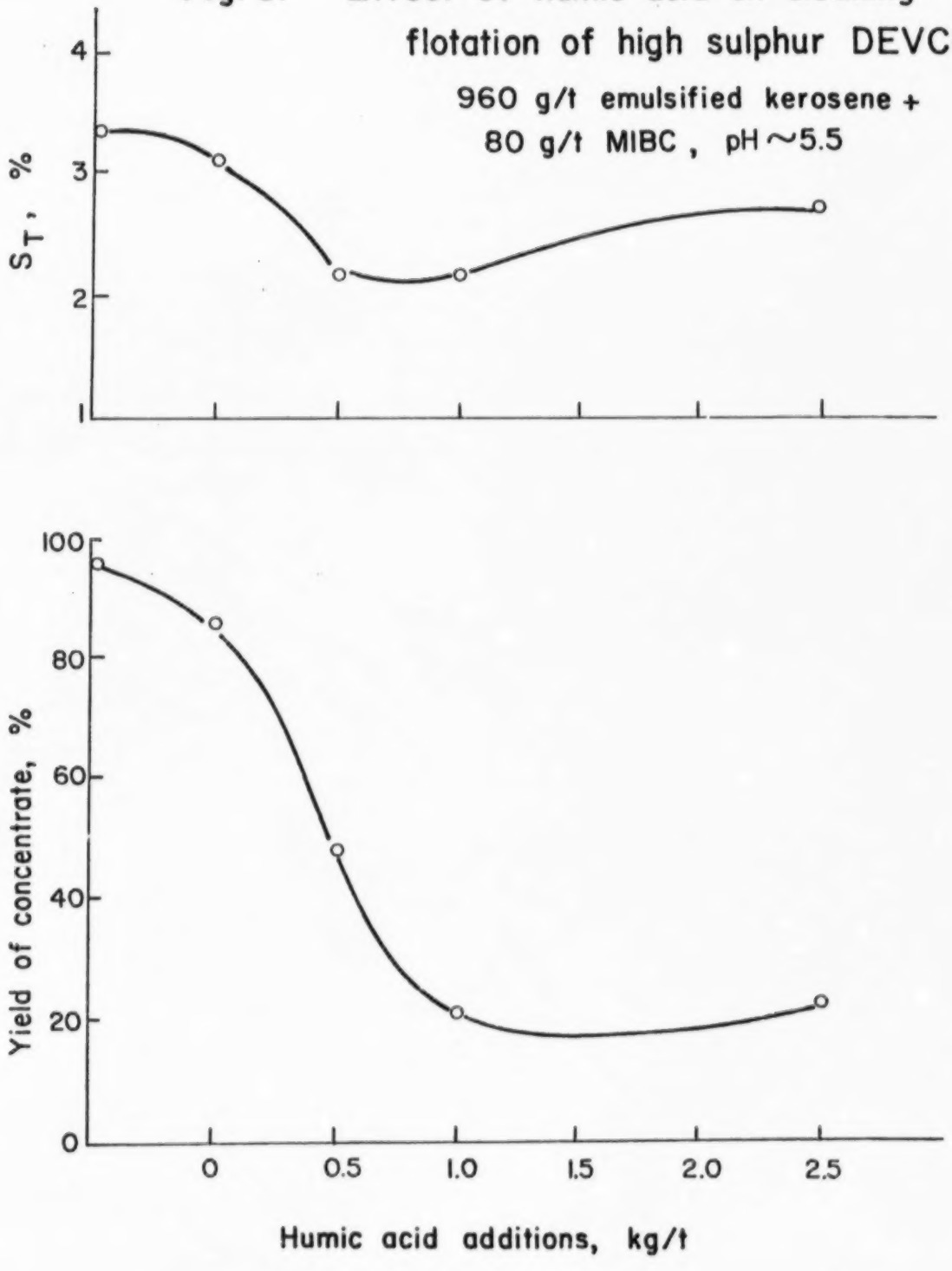


Fig. 33 Effect of humic acid on cleaning flotation of high sulphur DEVCO coal
960 g/t emulsified kerosene + 80 g/t MIBC

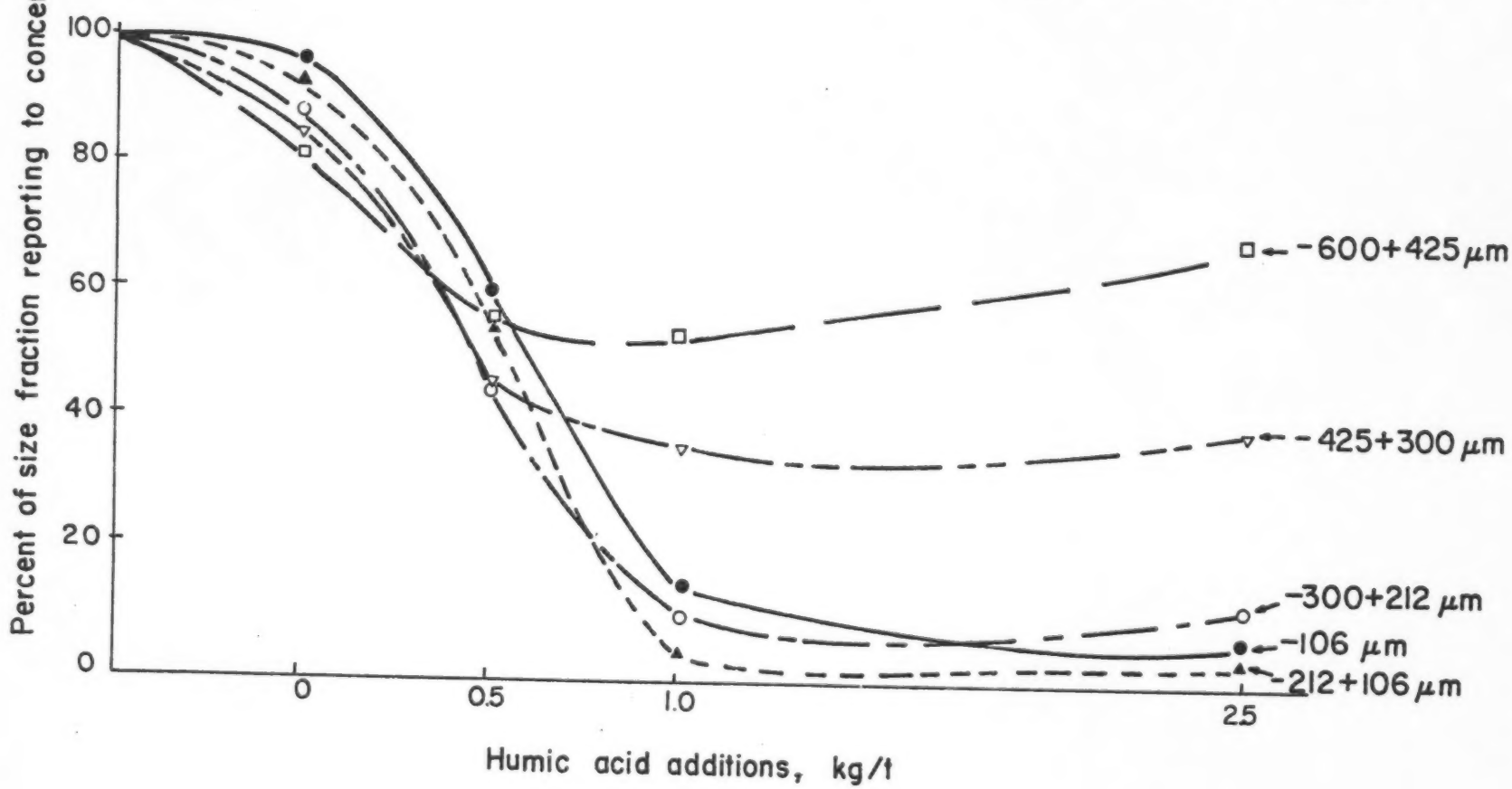


Fig. 34. Flotation kinetics of low sulphur DEVCO coal

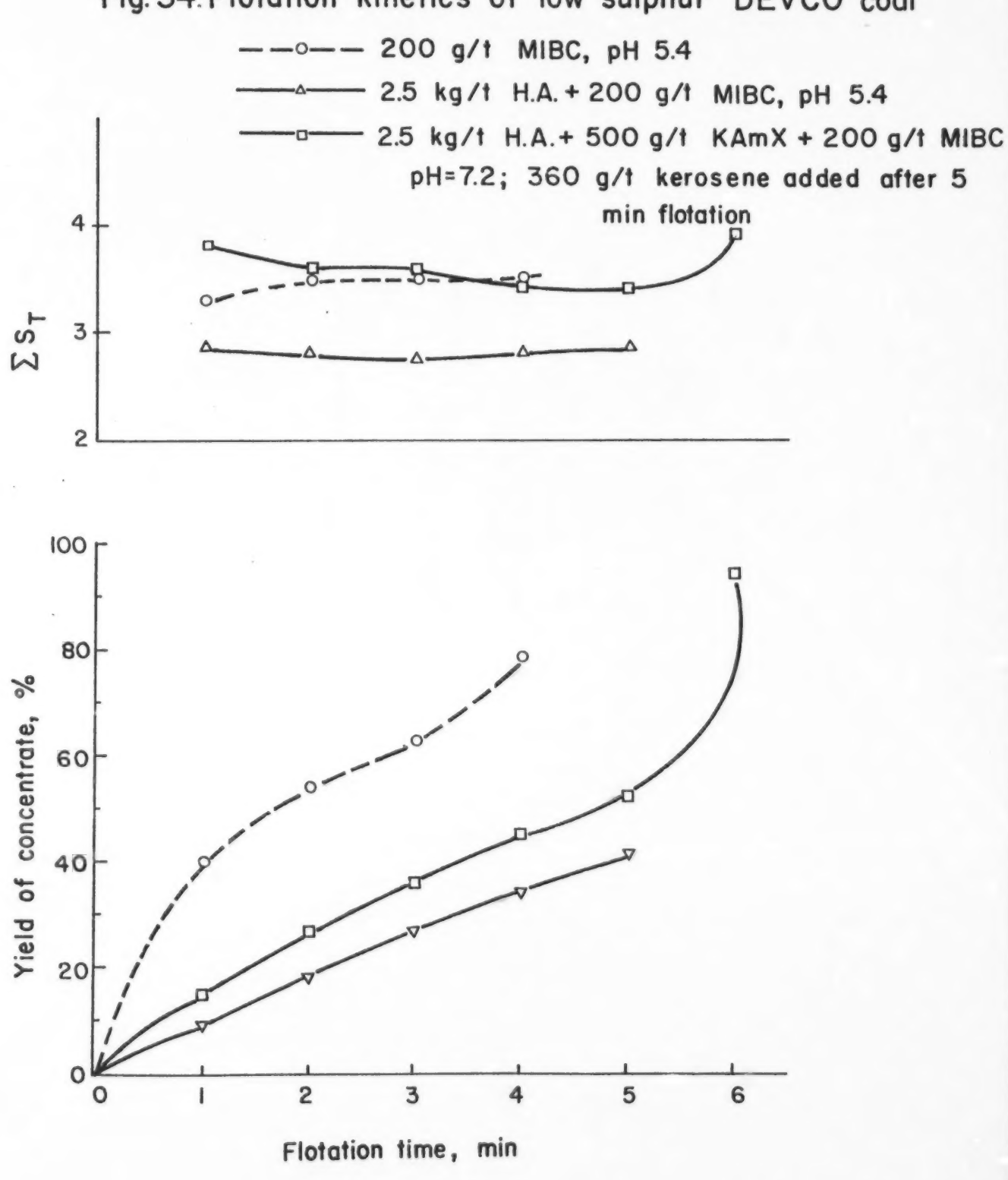
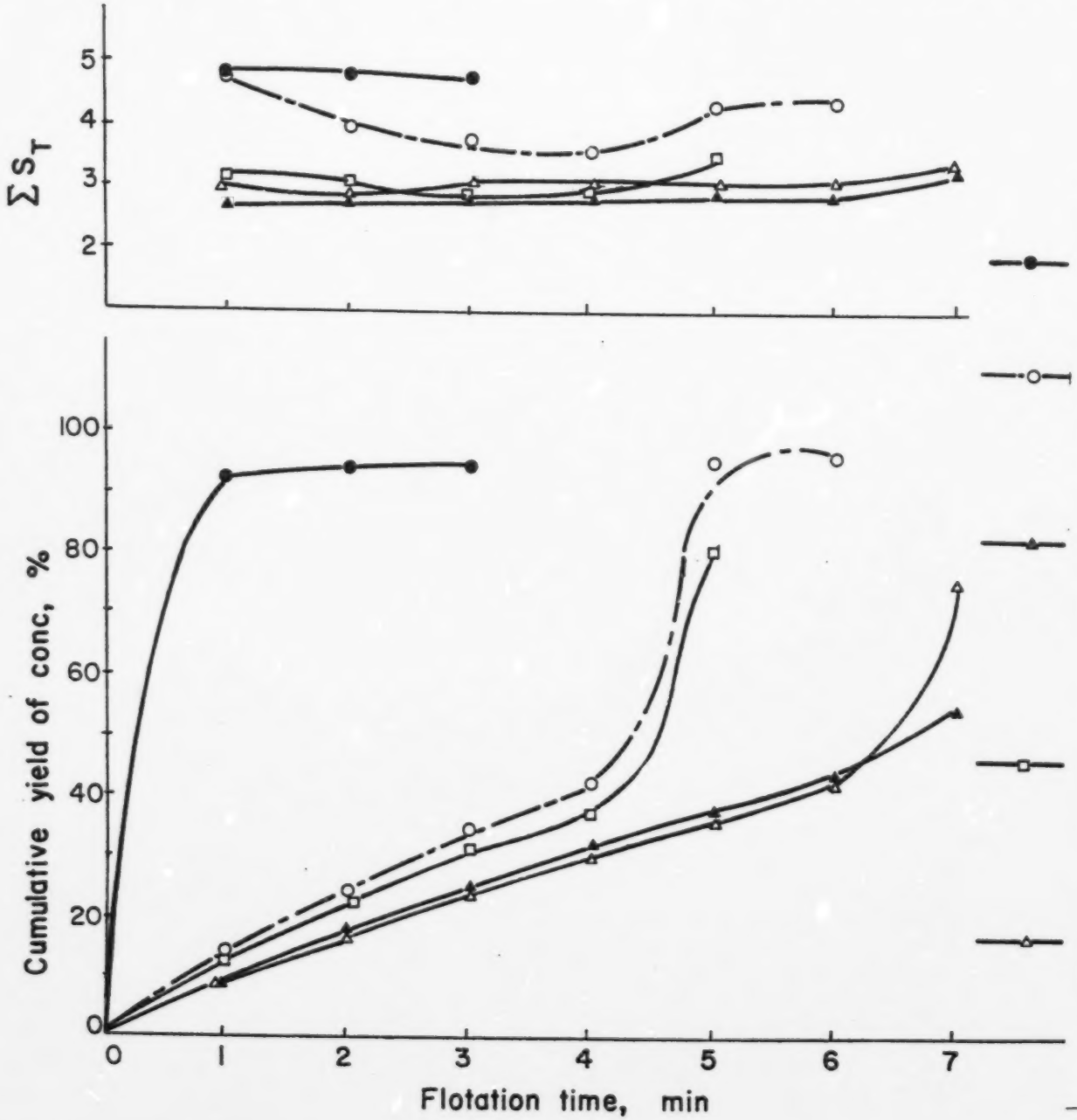

200 g/t MIBC, pH 5.4
2.5 kg/t H.A. + 200 g/t MIBC, pH 5.4
2.5 kg/t H.A. + 500 g/t KAmX + 200 g/t MIBC
pH=7.2; 360 g/t kerosene added after 5 min flotation
$\sum S_T$
Yield of concentrate, %
Flotation time, min

Fig. 35 Kinetics of flotation of DEVCO Low Sulphur Coal



Conditioning time and order of reagents addition:

- 9 min pulp, 300 g/t emuls. kerosene 1 min, 200 g/t MIBC 30 sec, pH 5.7
- 5 min pulp, 2.5 kg/t humic acid 4 min, 250 g/t KAmX 2 min, 200 g/t MIBC 30 sec, pH 6.2, 300 g/t emuls. kerosene and 200 g/t MIBC added after 4 min flotation;
- 5 min pulp, 300 g/t em. kerosene 1 min, 200 g/t MIBC and 2.5 kg/t H.A. 1 min, pH 6.1, 250 g/t KAmX added after 6 min flotation;
- pulp 5 min, 2.5 kg/t H.A. and 500 g/t KAmX 2 min, 200 g/t MIBC 30 sec., pH 5.8, 300 g/t em. kerosene and 100 g/t MIBC added after 4 min flot.
- pulp 5 min, 500 g/t KAmX 5 min, 2.5 kg/t H.A. 1 min, 200 g/t MIBC 30 sec, pH 6.1, 300 g/t em. kerosene and 100 g/t MIBC added after 6 min flotation